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B04C 9/00 // B04C 7/00

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B2P P2

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WPI Abstract Accession No 1993-335367 & SU001769963
WPI Abstract Accession No 1989-157472 & SU001437094

(58) Field of Search
UK CL (Edition T) B2P
INT CL[7] B04C
ONLINE: WPI, JAPIO, EPODOC

(54) Abstract Title
Multiple cyclone separation unit

(57) A multistage air-particle separator comprises at least two separation stages in (18, fig 1) 114 which particle-laden air is drawn through a succession of chambers in turn by suction applied to the last of the chambers. Heavier than air particles are separated from the airstream in each chamber by centrifugal force, and conveyed to a collecting bin (26 or 66, fig 1) and particle depleted air is drawn from each chamber by suction. An intermediate separation stage comprises a cylindrical chamber, having a port (48, fig 10) through which air from an earlier stage enters the chamber. The port is arranged so that air entering the chamber does so generally tangentially, and a hollow spindle 90 extends centrally of the chamber and communicates with an opening in a closed end wall of the chamber, leading to the next separation chamber. A turbine 94, 96 is mounted for rotation about the chamber axis and is generally aligned with the port through which air enters the chamber, the incoming air causing the turbine to rotate. At least one opening 62 is provided at or near the end of the hollow spindle through which air can leave the chamber to pass therealong into the next separation stage, and a particle collecting bin (66, fig 1) is provided at the end of the chamber remote from the turbine. The hollow spindle may be stationary and the turbine rotates therearound, or the turbine is attached to the spindle so that the two rotate together. Small openings may be provided in the spindle wall around one end thereof, in which event the turbine is mounted at a position axially distant from the openings. The turbine containing region of the chamber may be separated from the region of the chamber which communicates with the interior of the hollow spindle, by means of an annular baffle 88 containing at least one opening therein through which air can pass from the one region to the other. The rotating spindle imparts rotation to the air passing into the next chamber. In this last chamber the air enters axially and is deflected on entry. A first exit port 118 removes clean air to the suction source 10. A second port 112 may be provided in the wall of the chamber circumferentially spaced from the first port, to allow particles separated in the final stage to be returned via a passage for separation in the rotating airstream in the intermediate chamber. Collecting bin (26, fig 1) is separated from the cyclone chamber (18, fig 1) by a baffle (56, fig 1) to prevent the re-entrainment of

(57) continued overleaf

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(57) cont

particles. Collecting bin (66, fig 1) may be replace by a valve (see fig 4) which is constructed such that downstream suction forces maintain it in a closed position during operation of the unit, but allows the valve to open when no suction is present. On openiong of the valve the collected particles are able to fall into the collecting bin (26, fig 1).

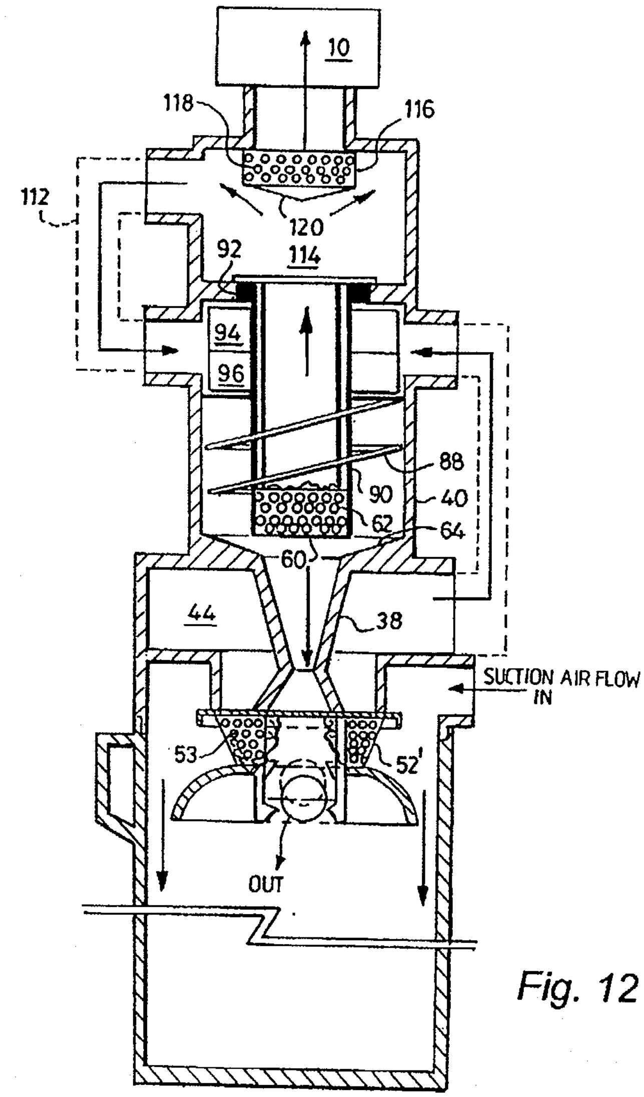
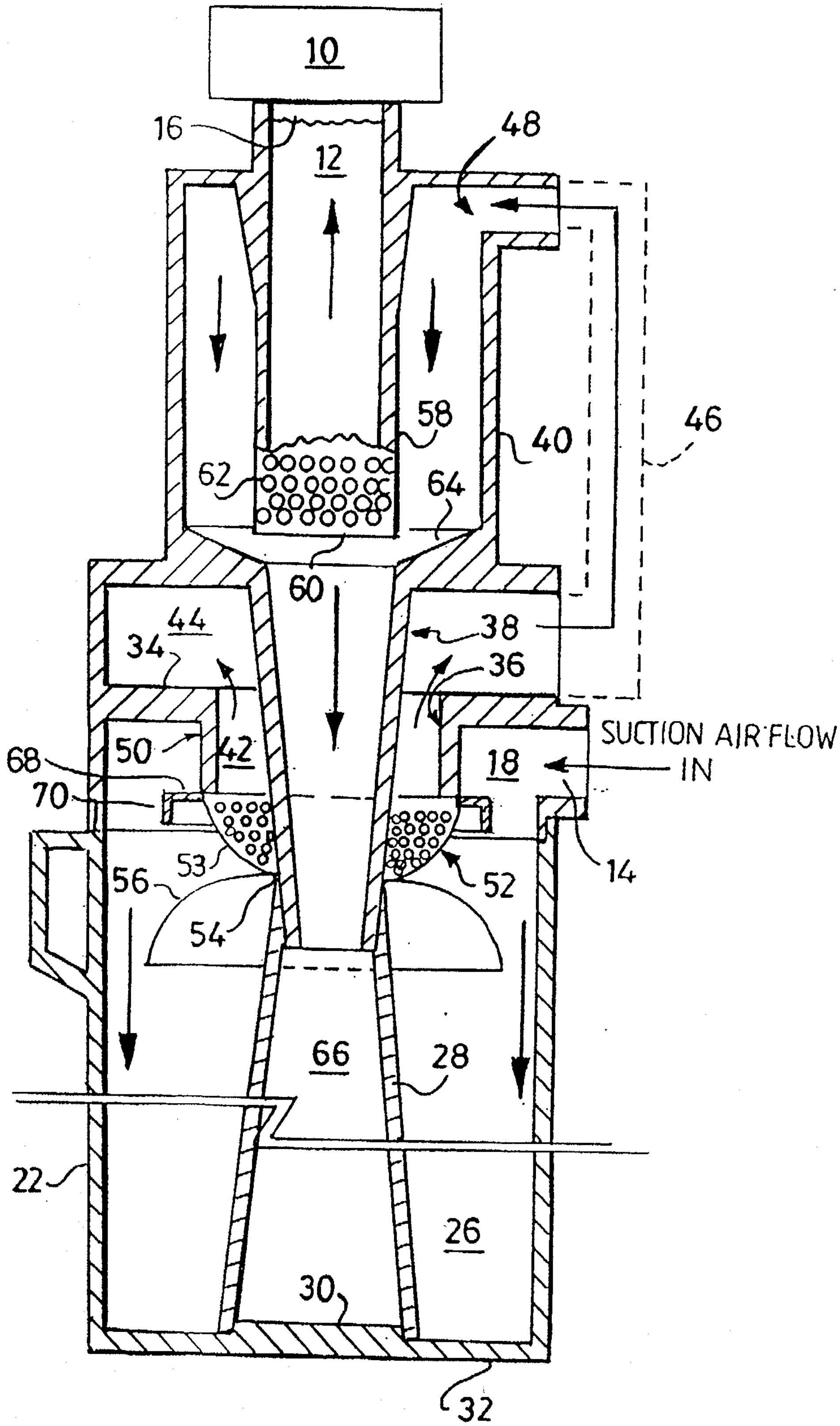


Fig. 12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SUCTION AIR FLOW IN
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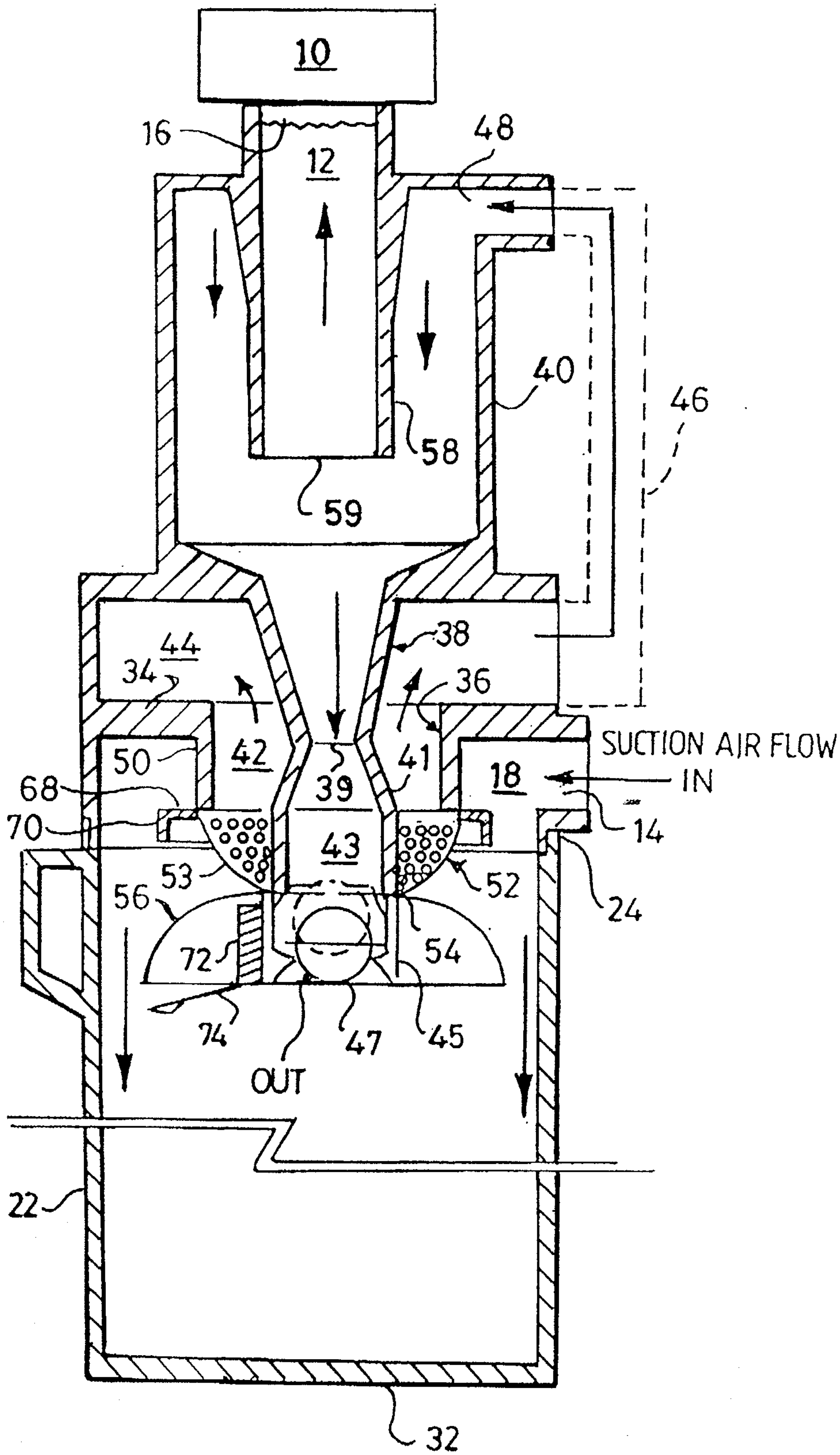
Fig. 1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SUCTION AIR FLOW
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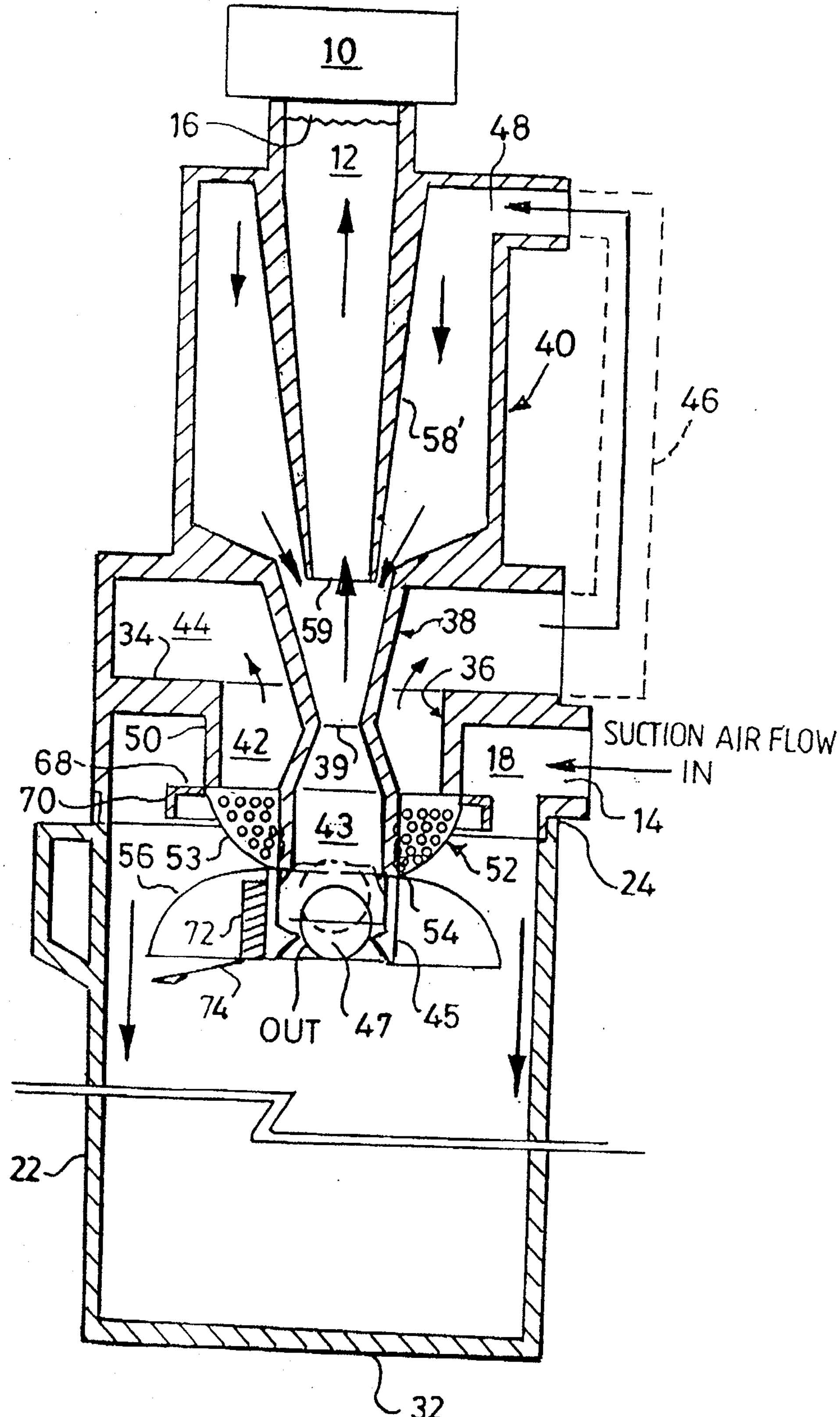
Fig. 2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74
OUT
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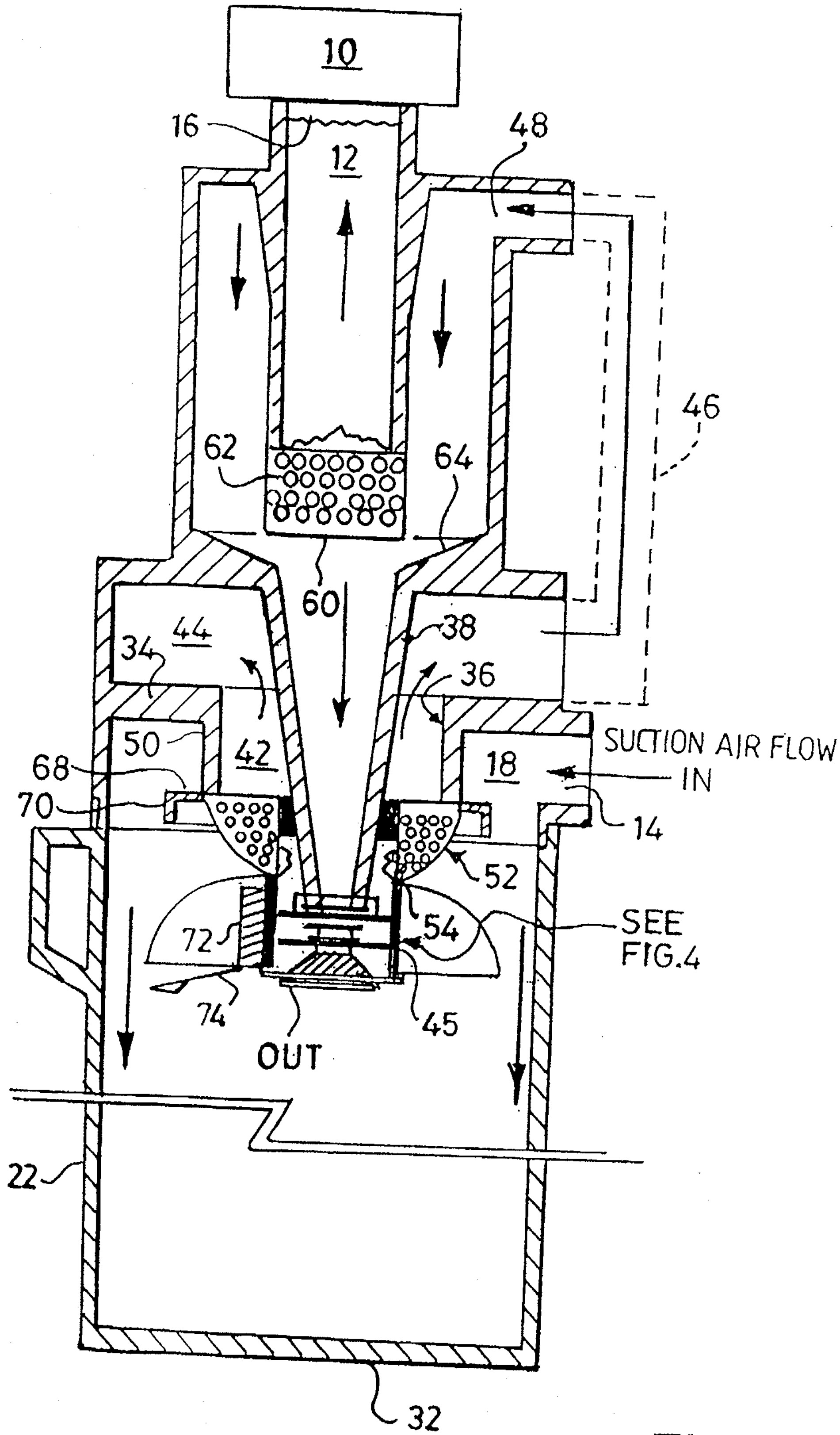
Fig.2A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SUCTION AIR FLOW IN
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72
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SEE FIG.4
74
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OUT
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32

Fig. 3

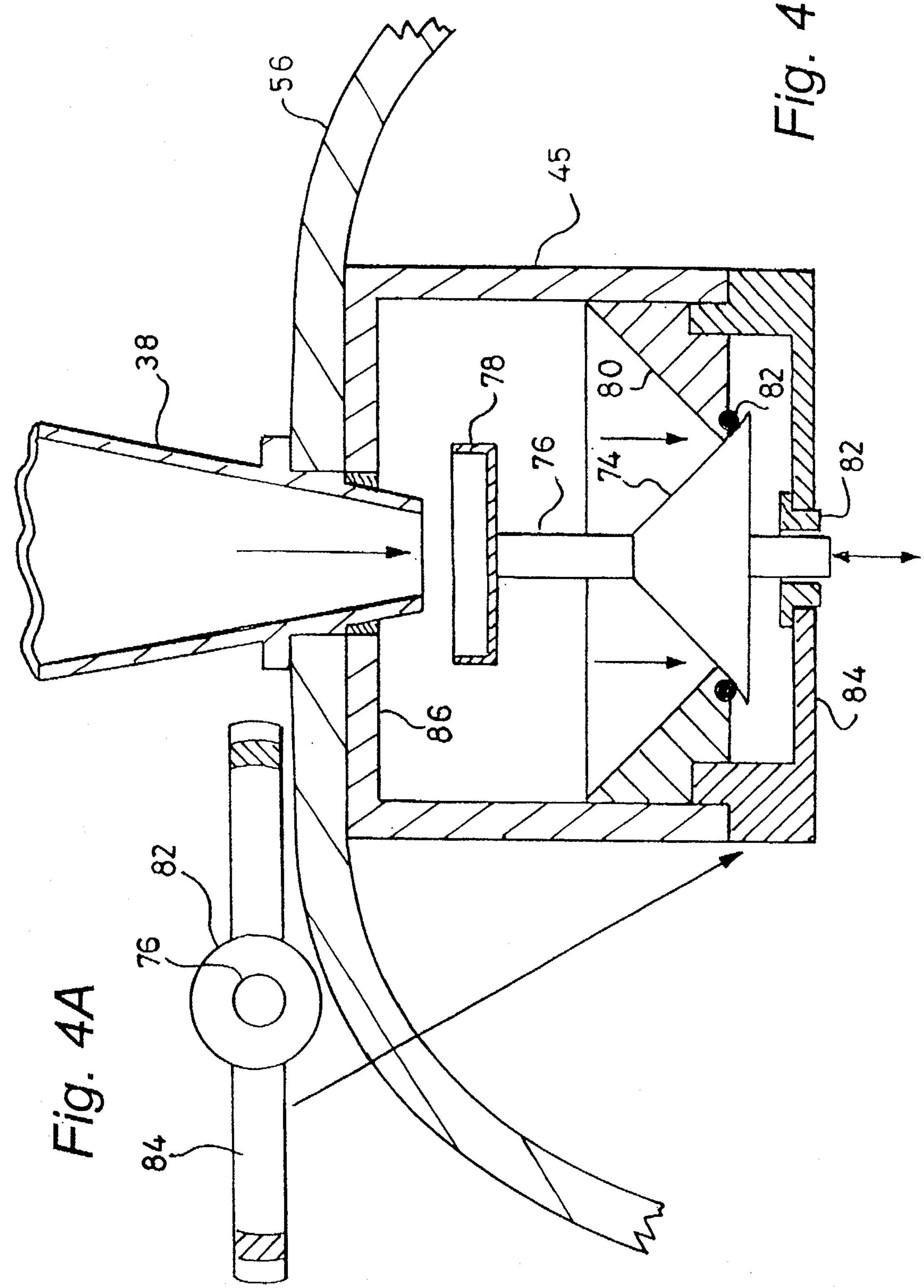
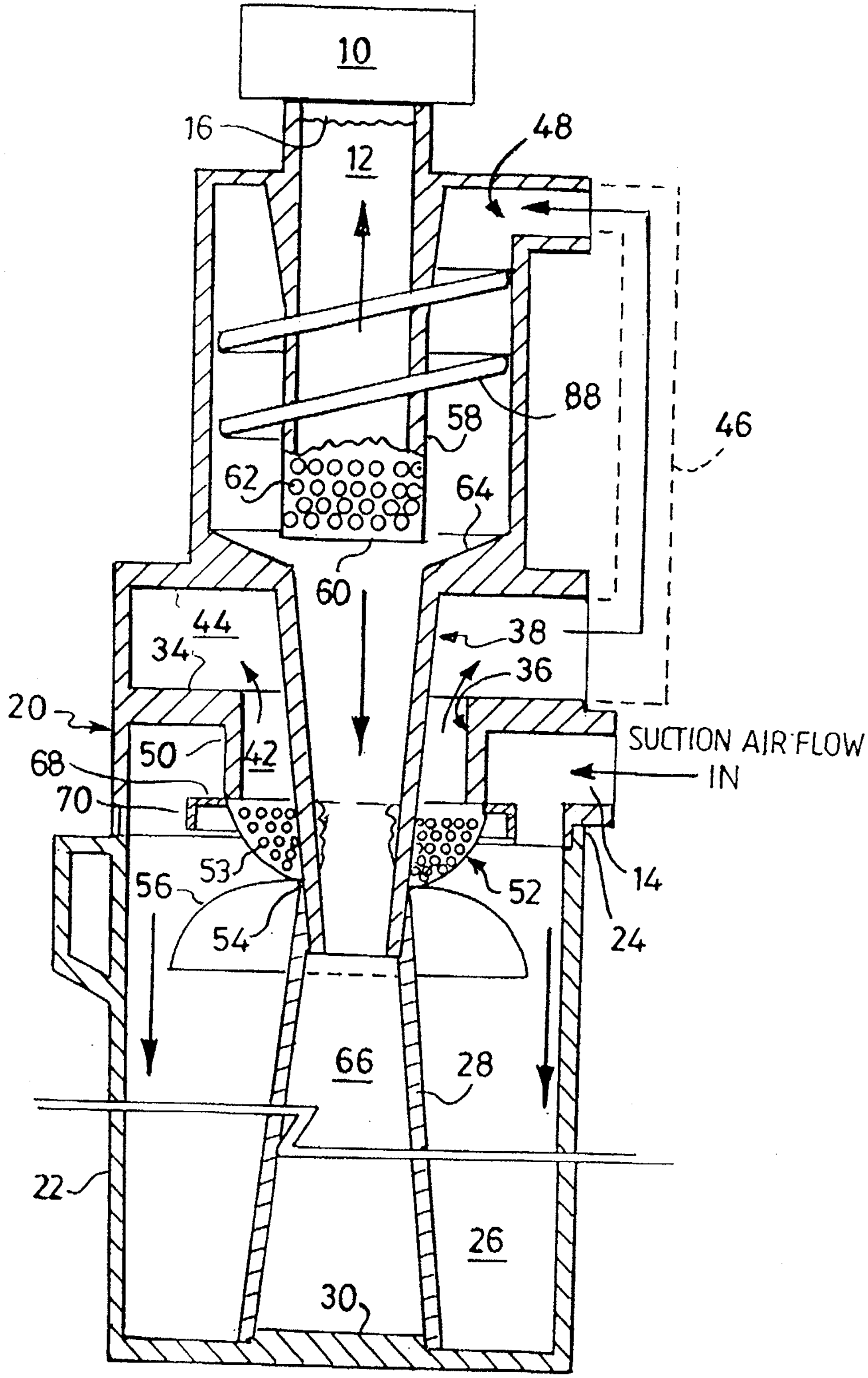


Fig. 4

Fig. 4A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SUCTION AIR FLOW
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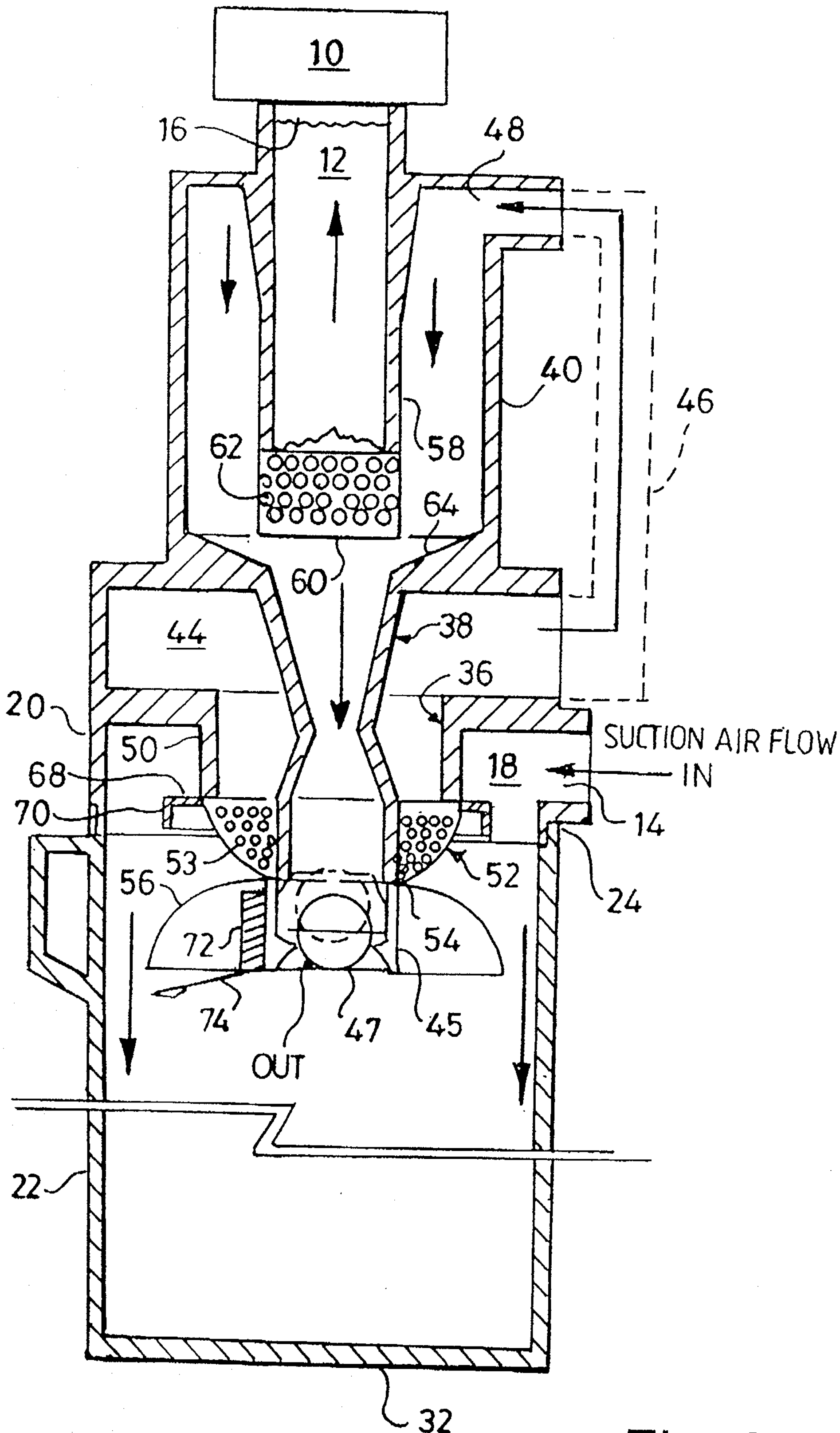
Fig. 5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SUCTION AIR FLOW
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74
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OUT
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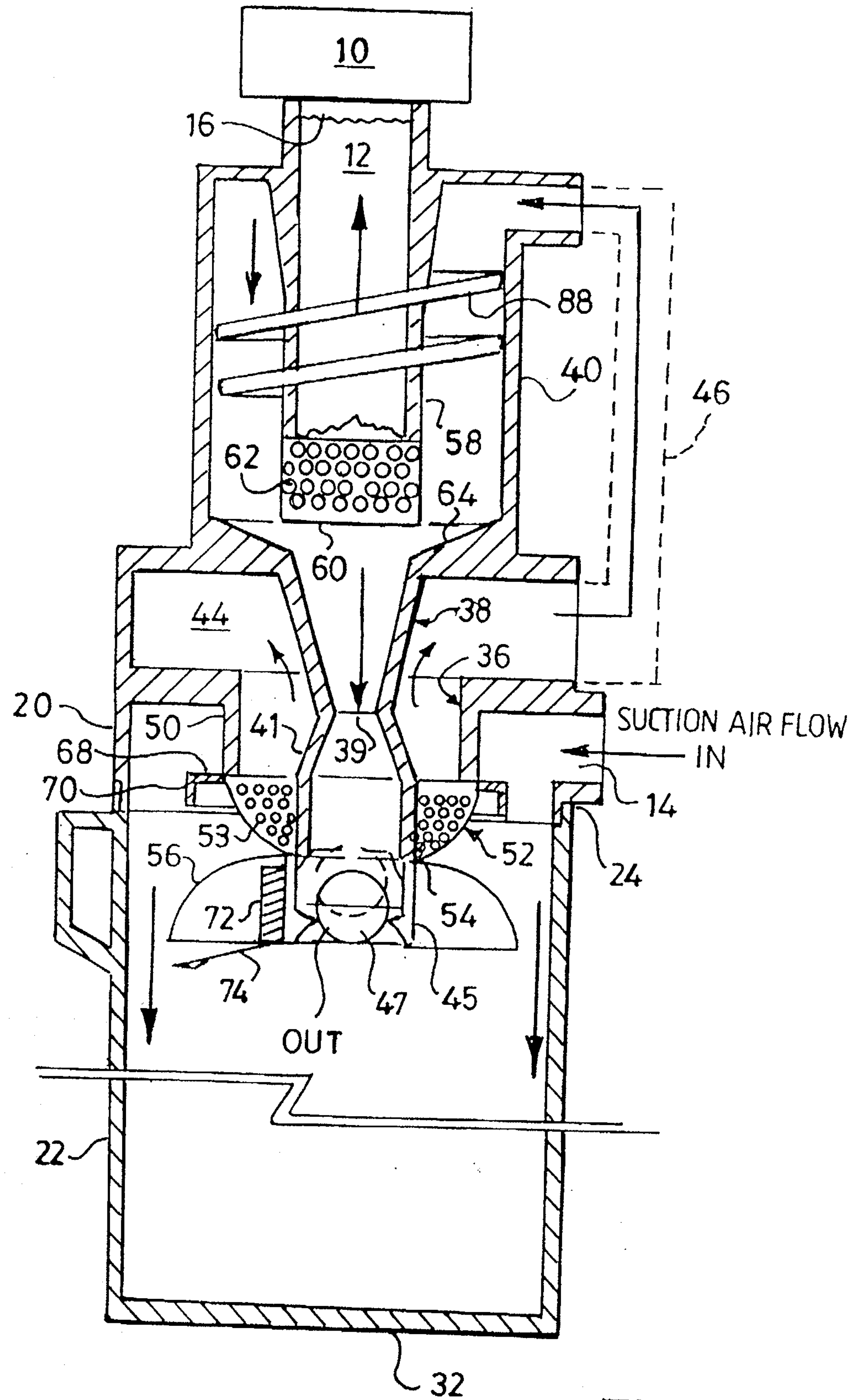
Fig. 6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SUCTION AIR FLOW
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OUT
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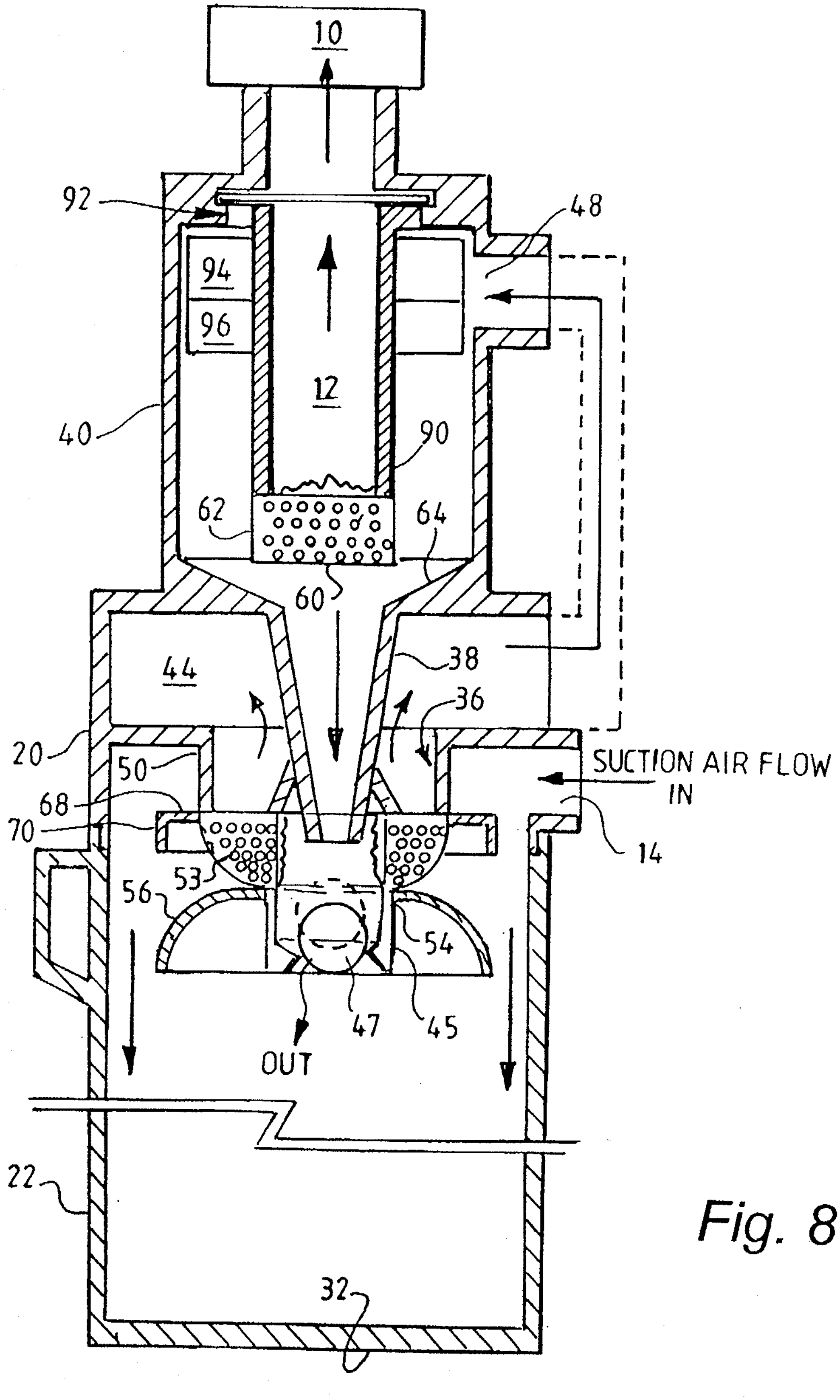
Fig. 7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SUCTION AIR FLOW IN
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OUT
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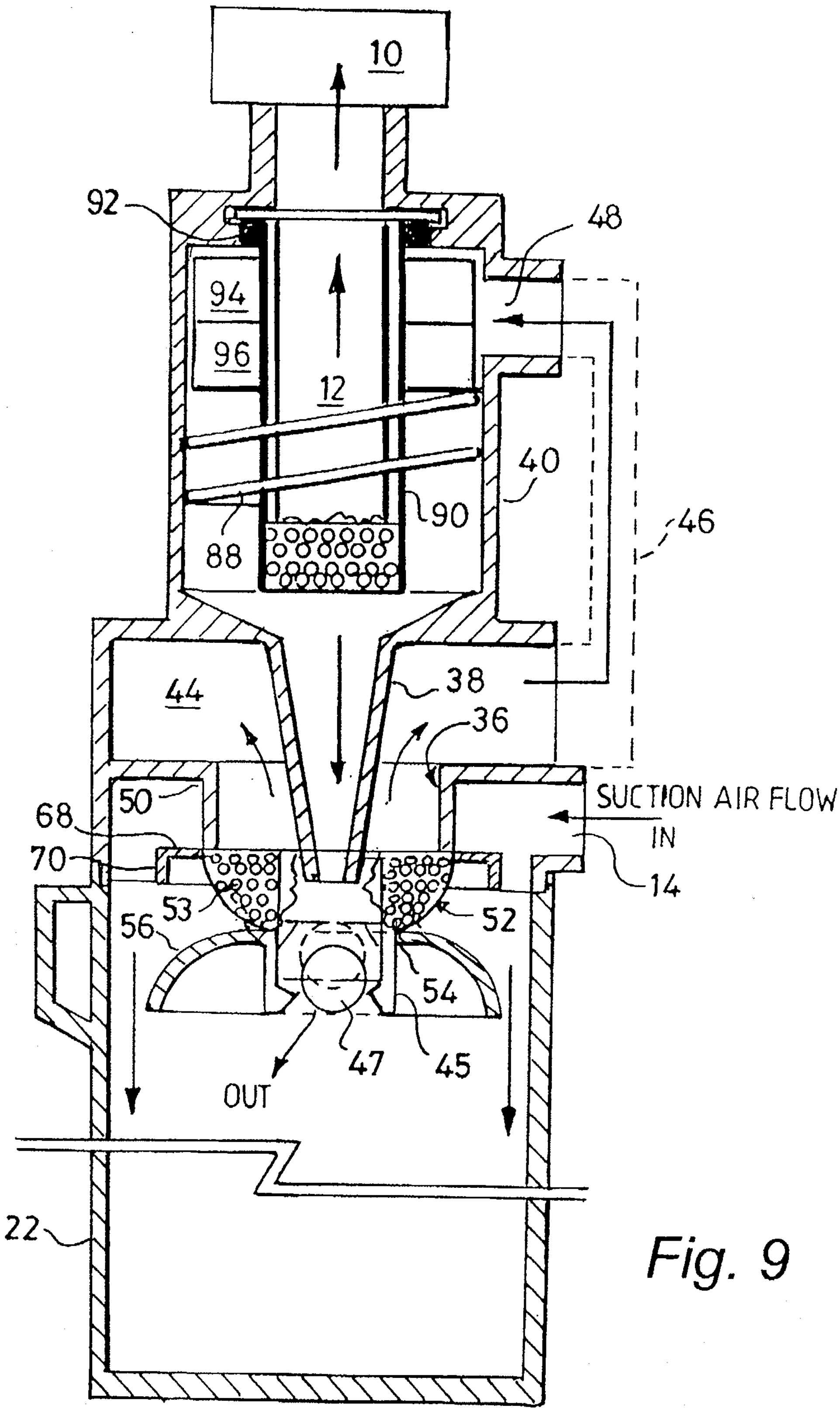
Fig. 8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90
46
88
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SUCTION AIR FLOW
IN
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56
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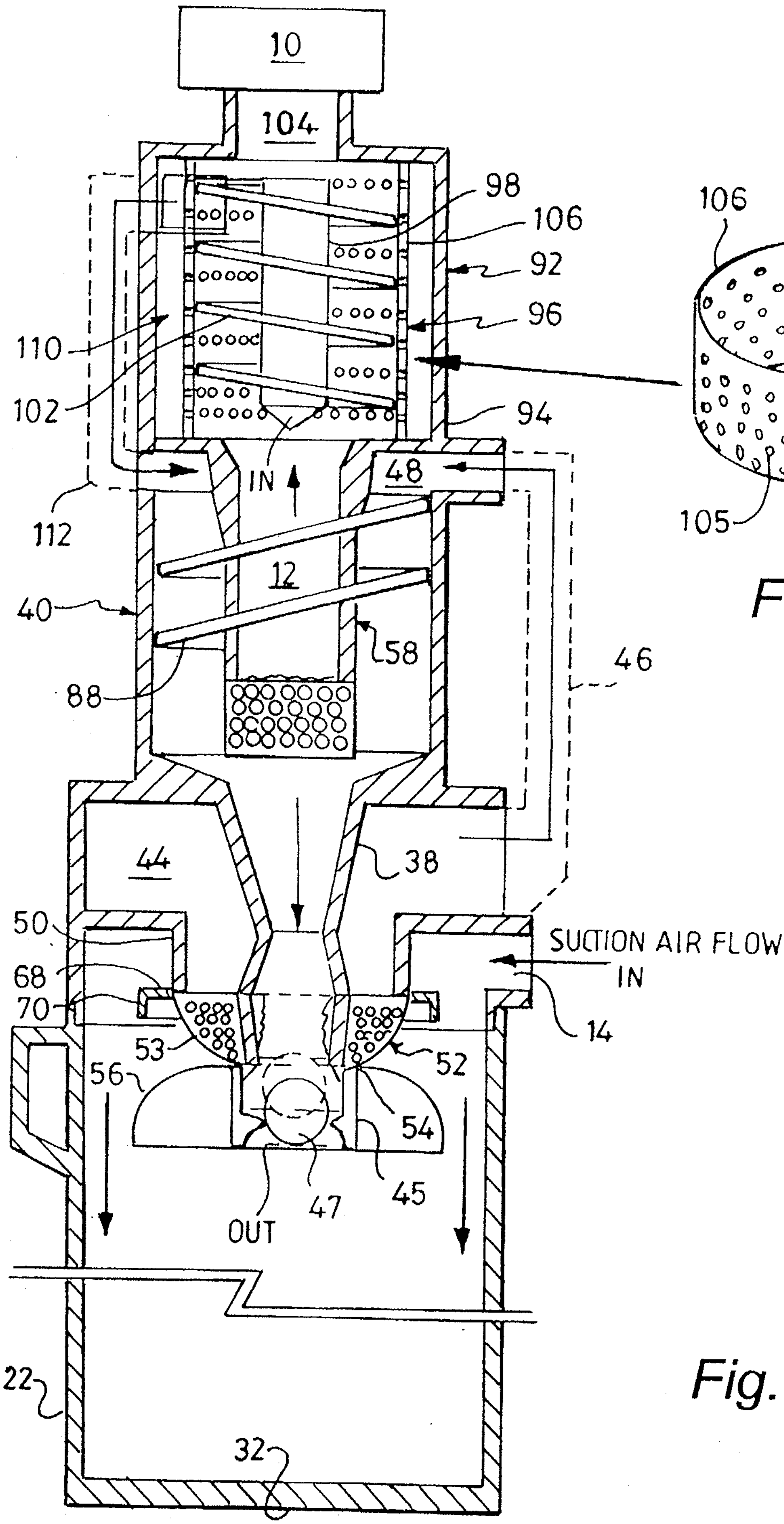
OUT
22

Fig. 9



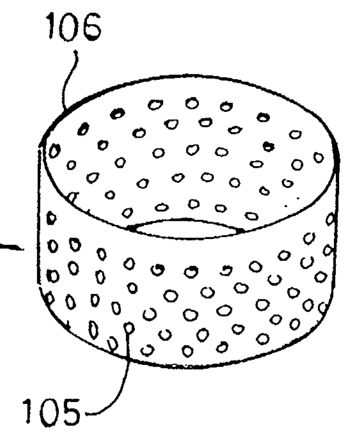


Fig. 10A

Fig. 10

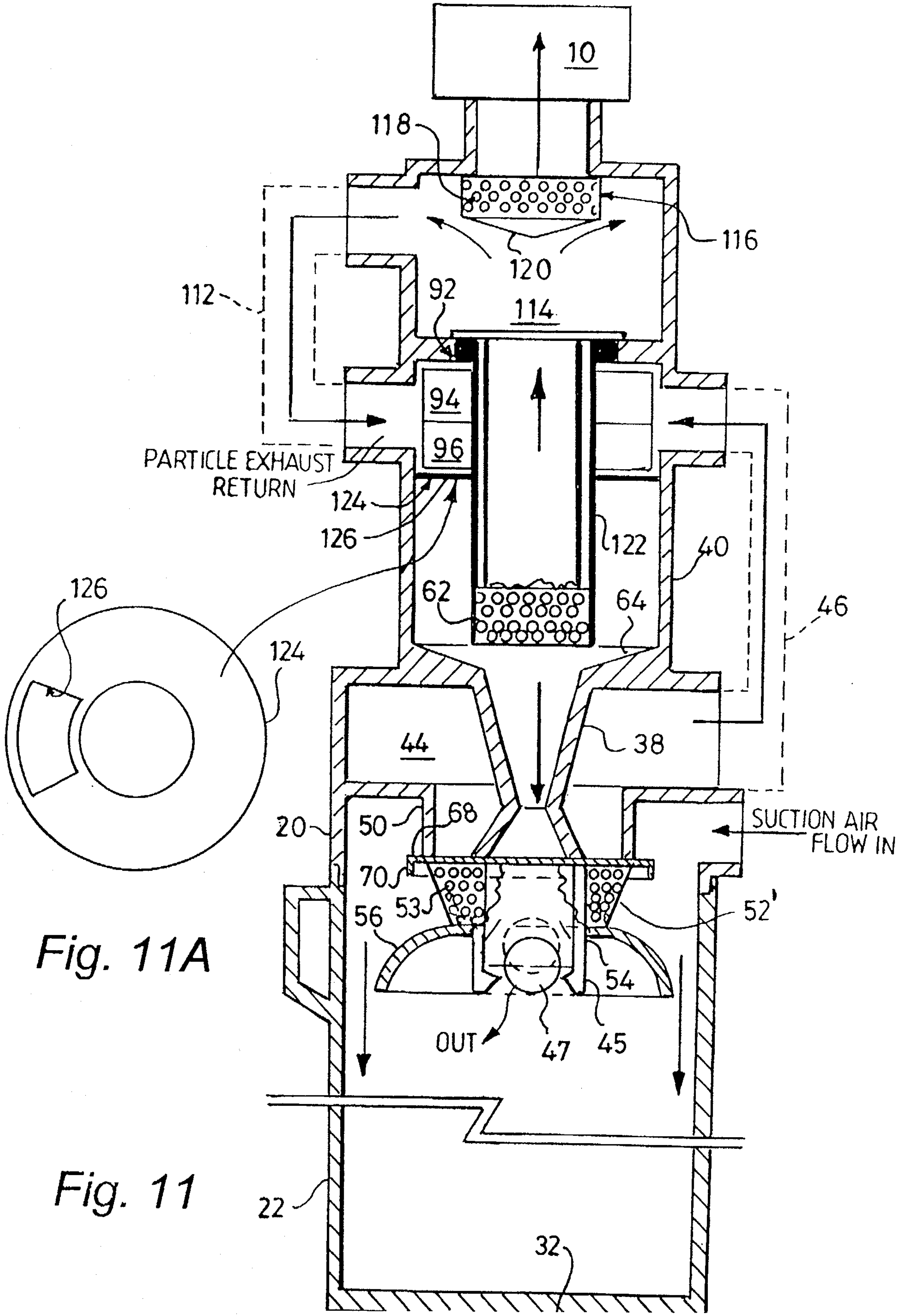
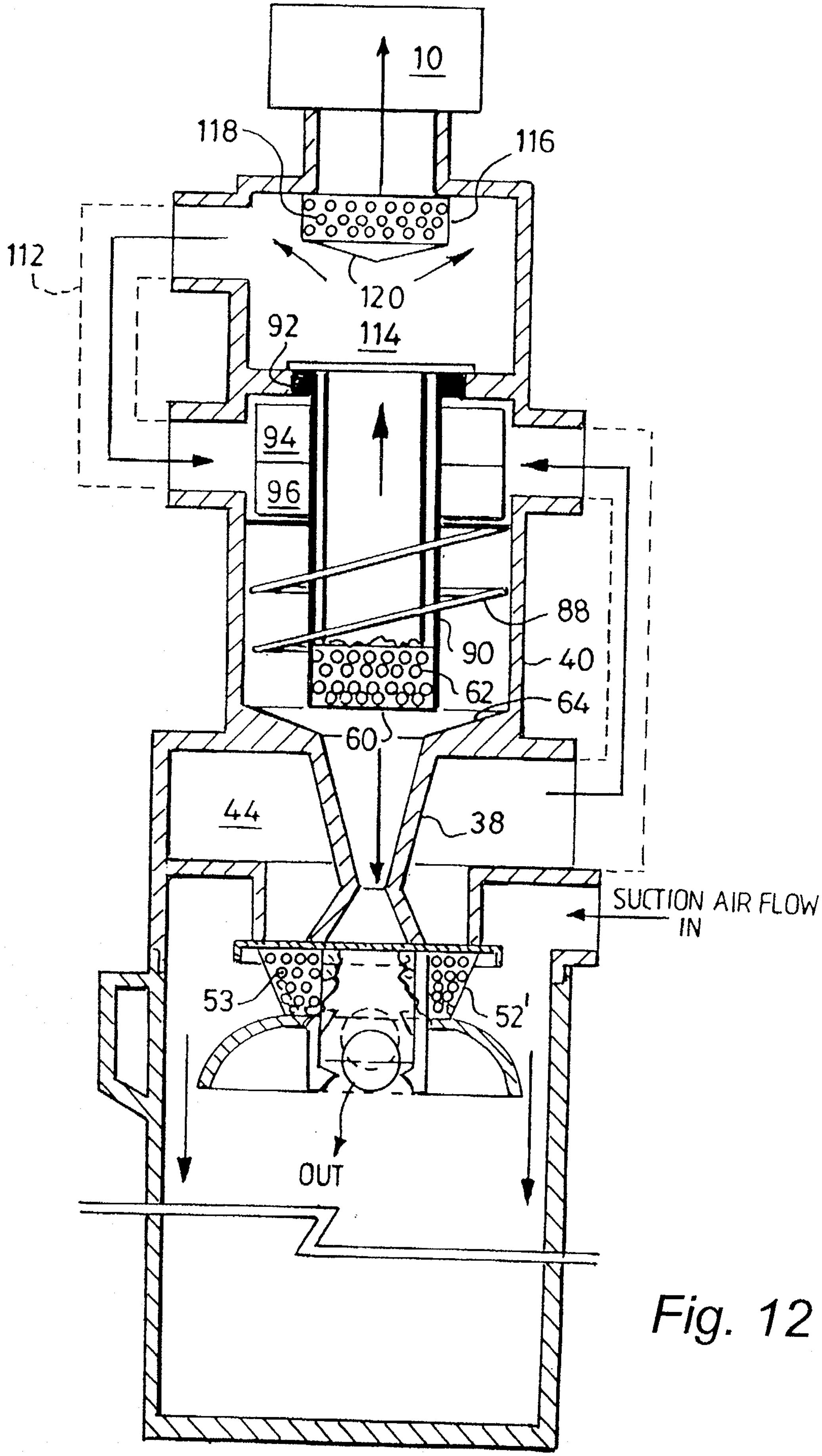


Fig. 11A

Fig. 11


10
118
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112
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44
38
SUCTION AIR FLOW IN
53
52'
OUT

Fig. 12

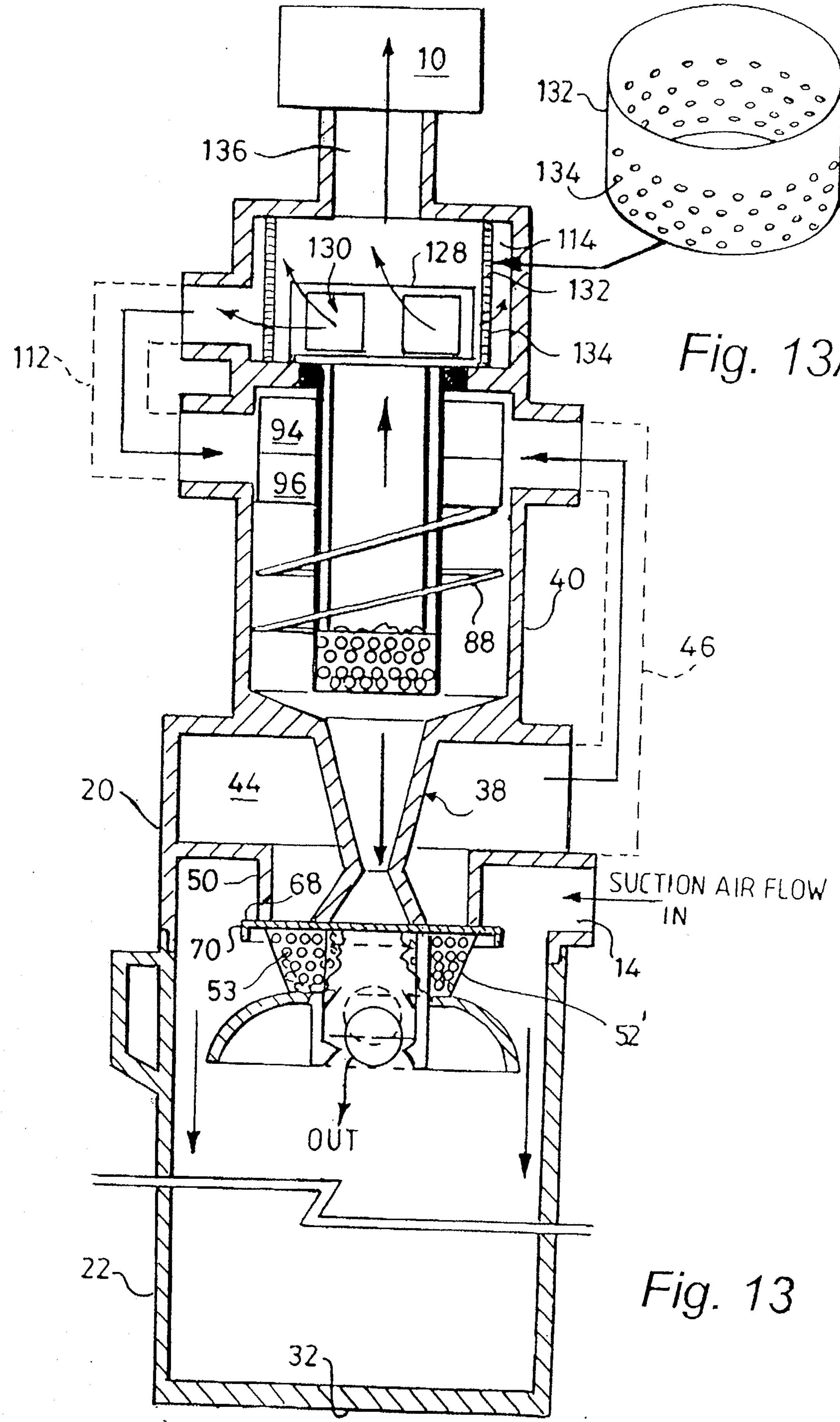
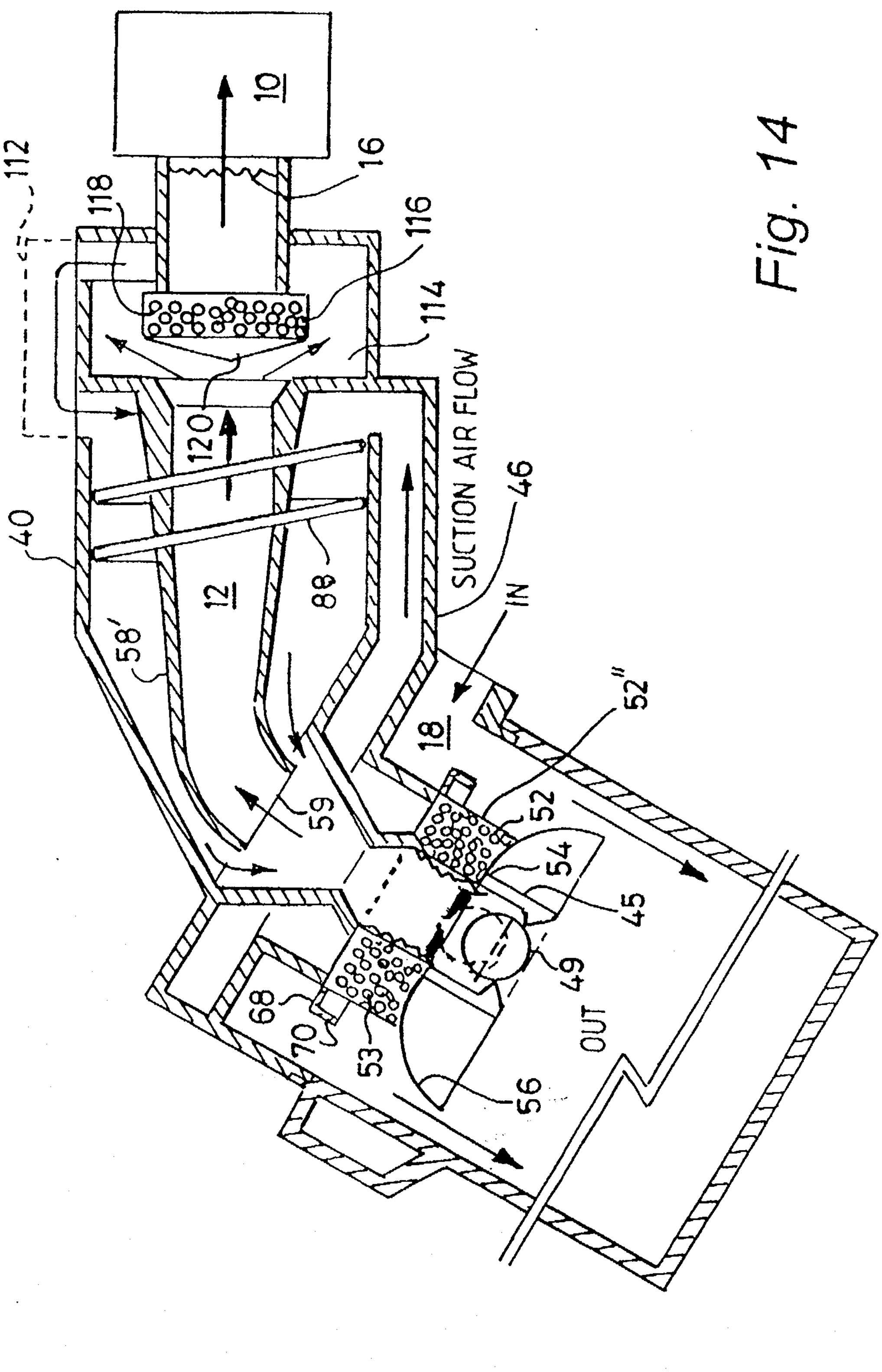


Fig. 13A

Fig. 13


112
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114
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12
88
SUCTION AIR FLOW
46
IN
58'
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52''
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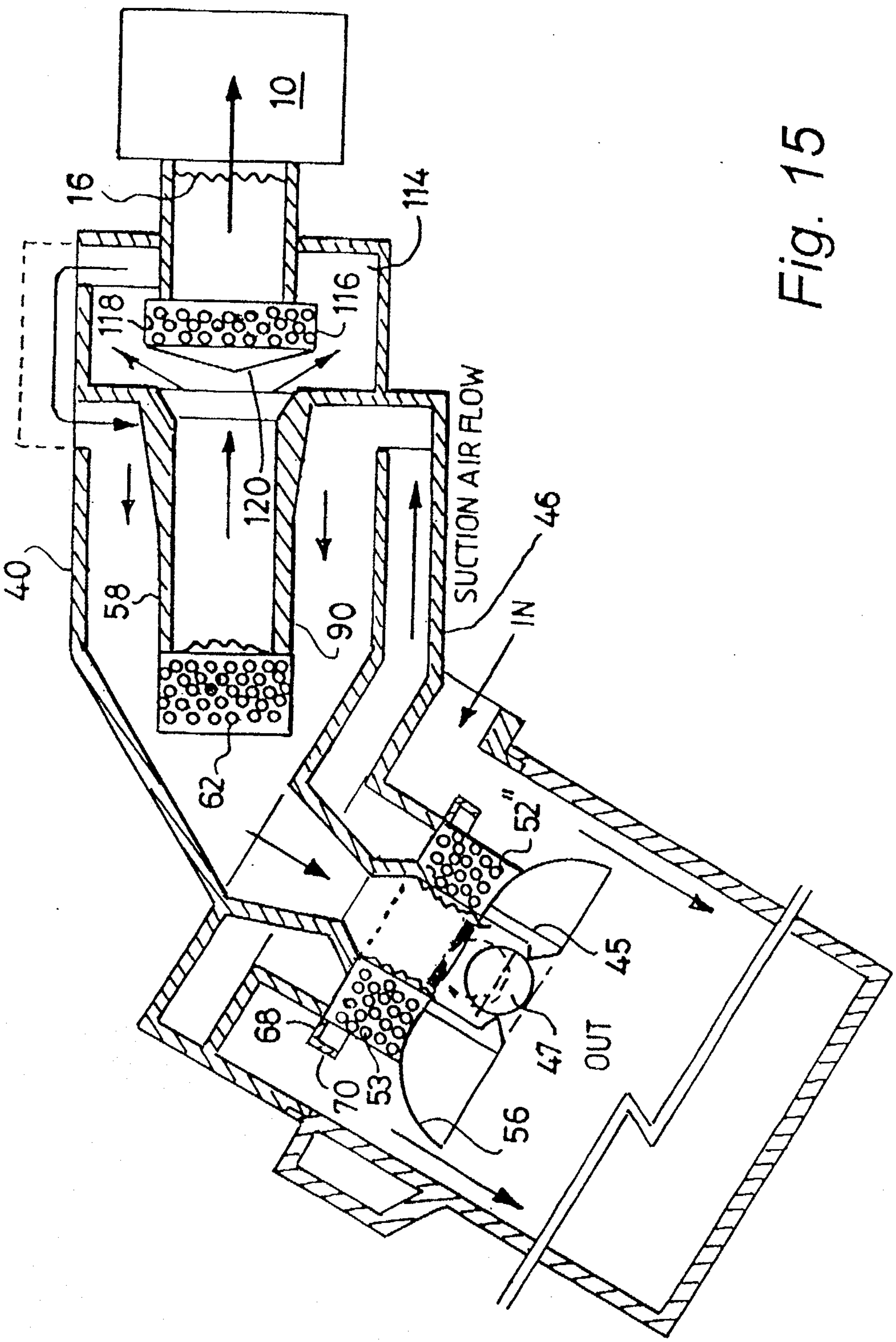
45
49
68
70
53
OUT
56

Fig. 14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SUCTION AIR FLOW
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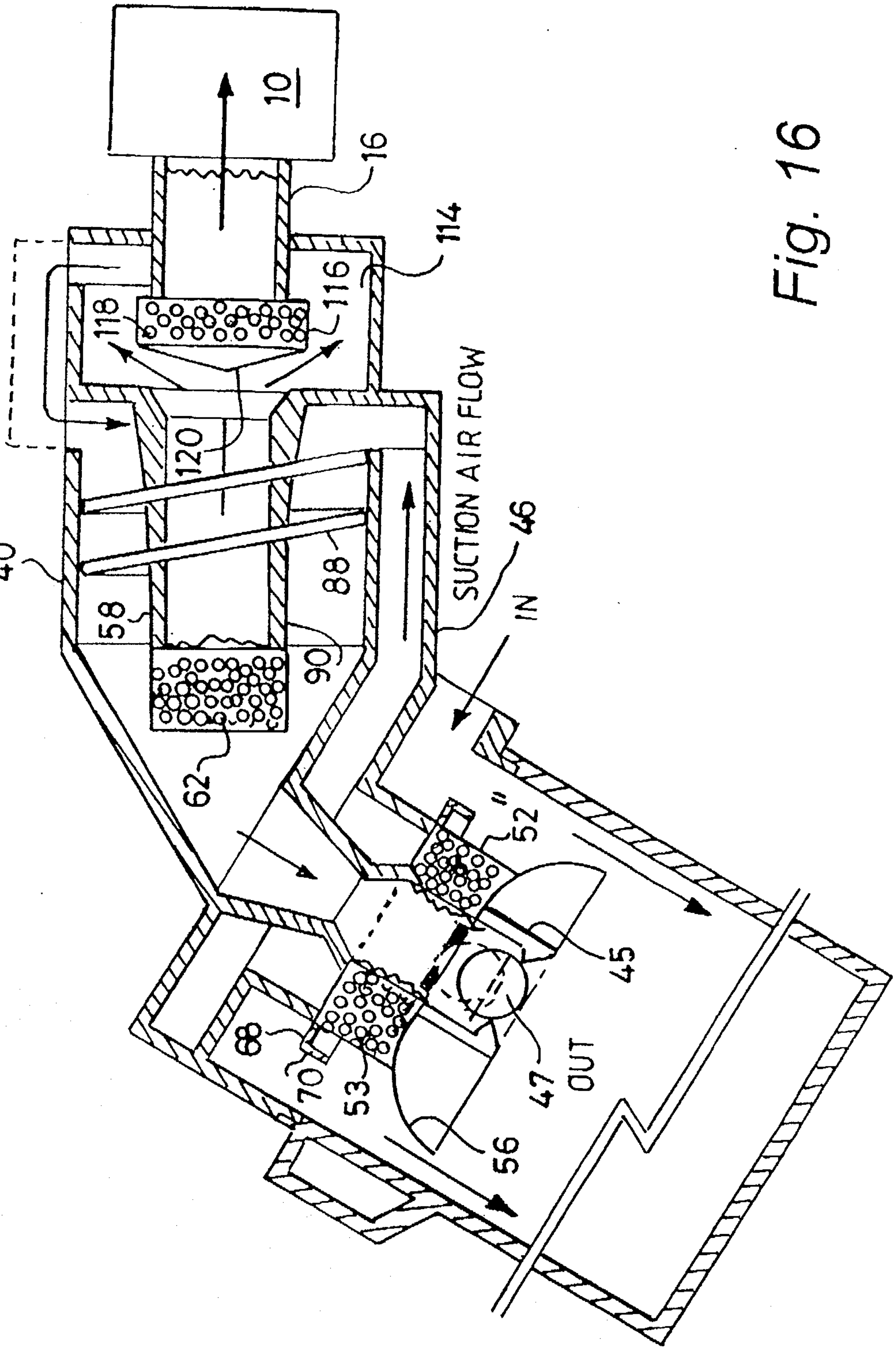
Fig. 15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SUCTION AIR FLOW
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Fig. 16

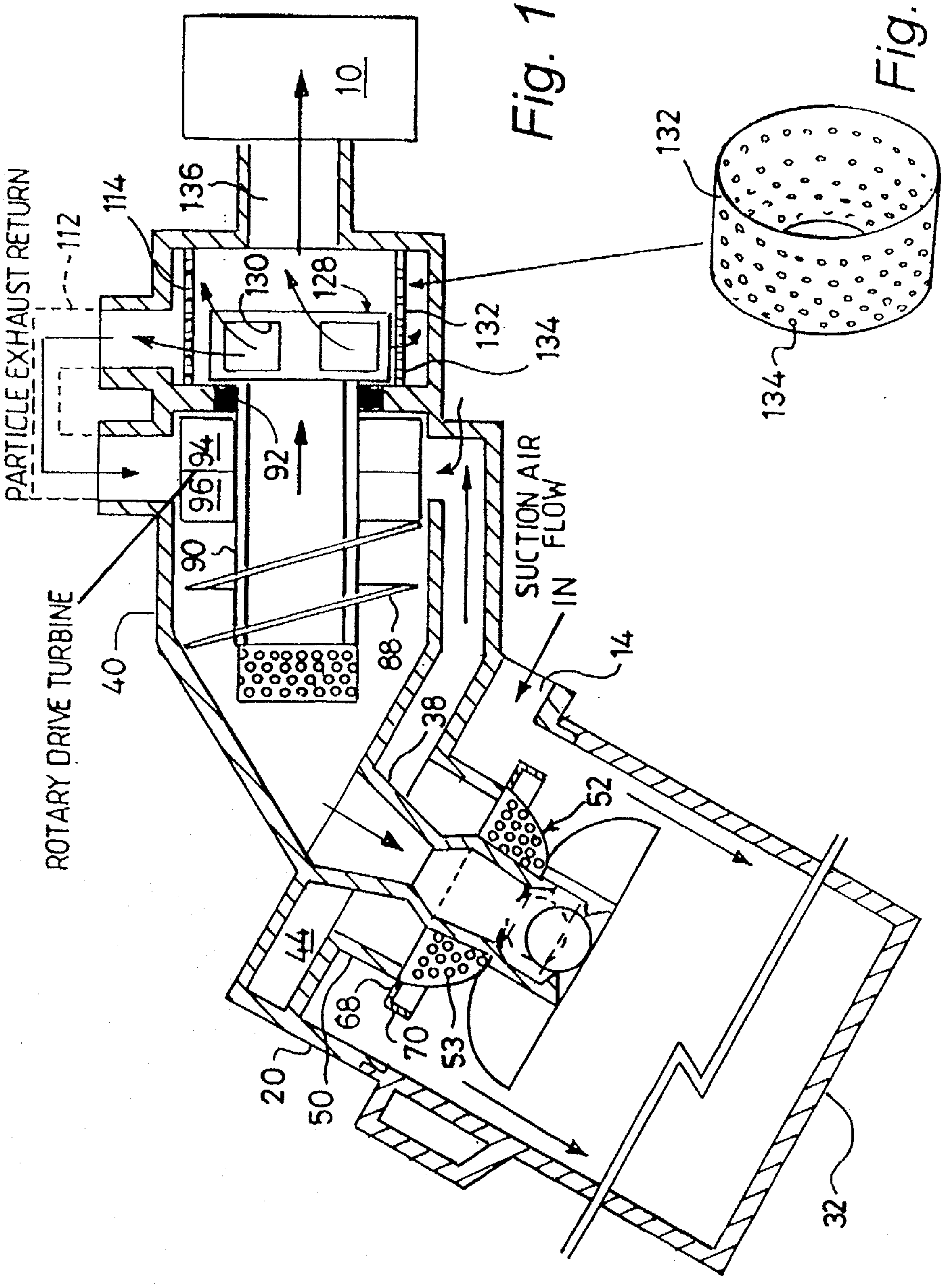

Fig. 17

Fig. 17A

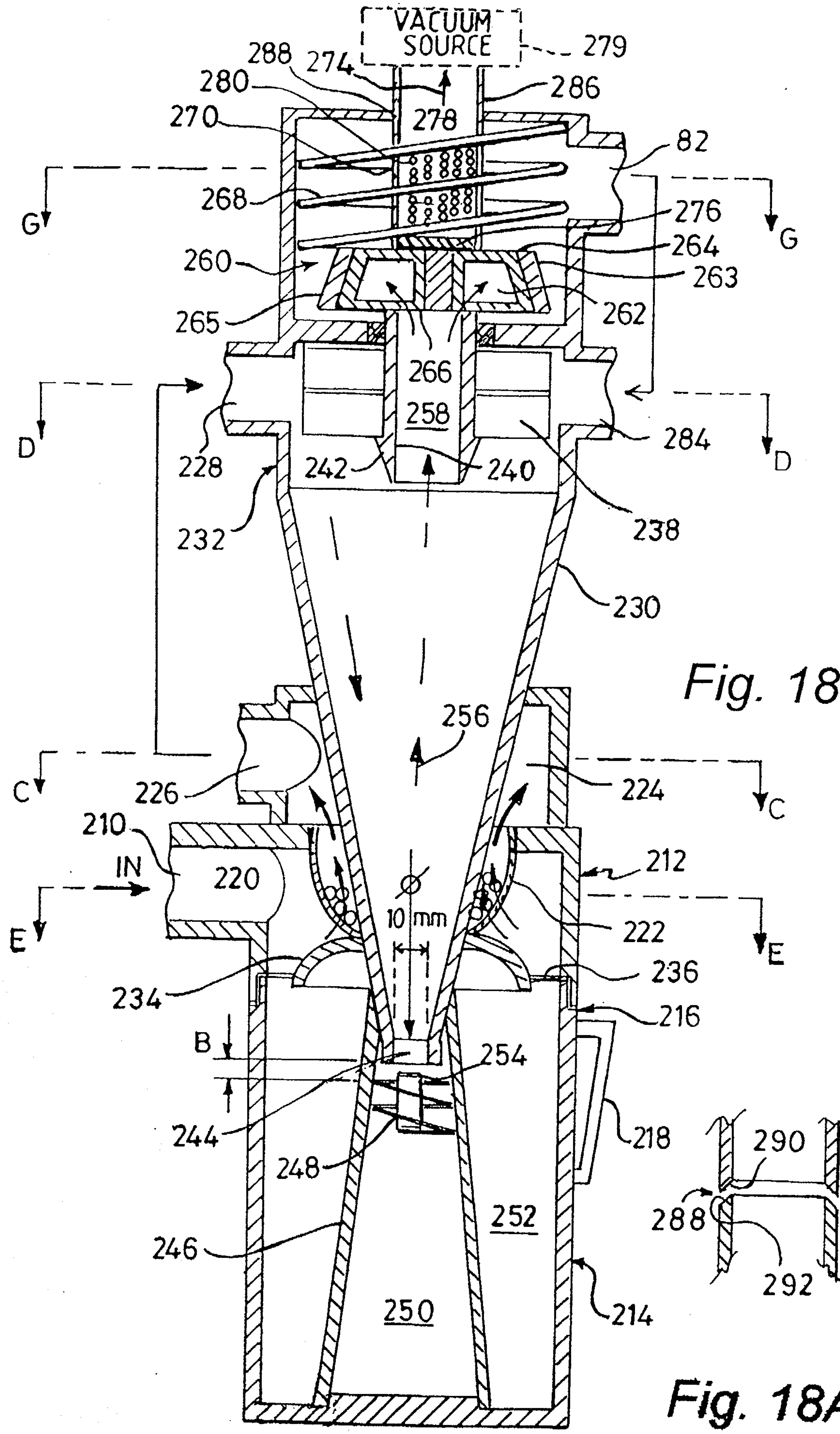

Fig. 18

Fig. 18A

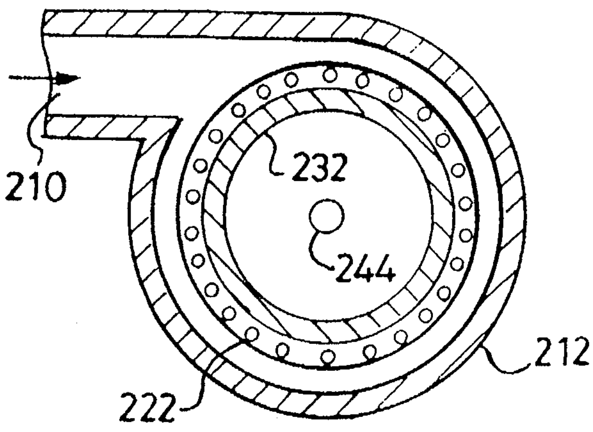

Fig. 18B

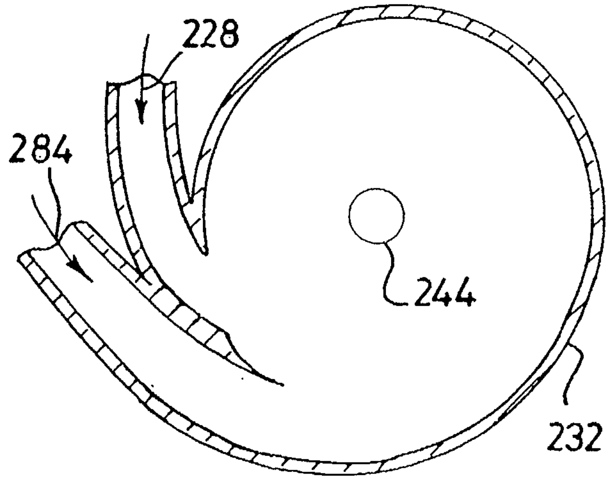

Fig. 18E

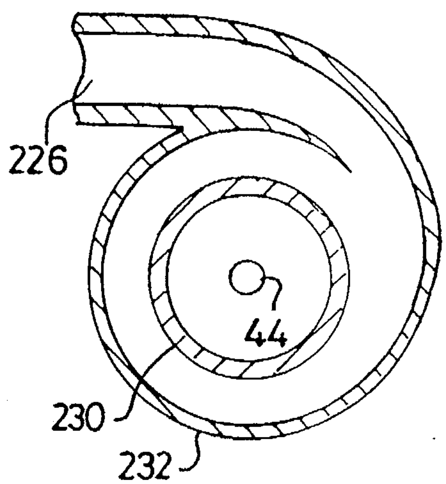

Fig. 18C

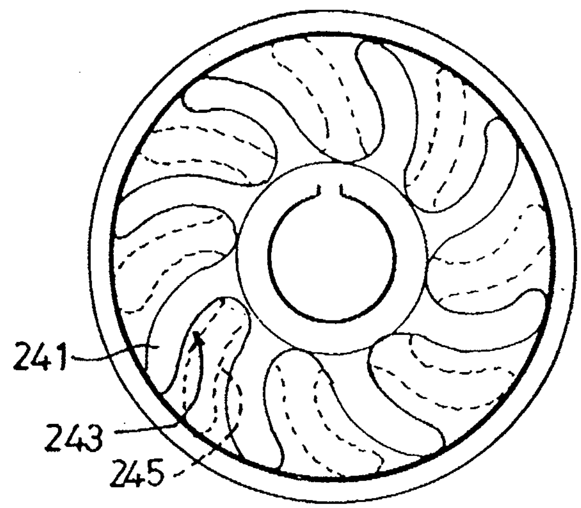

Fig. 18F

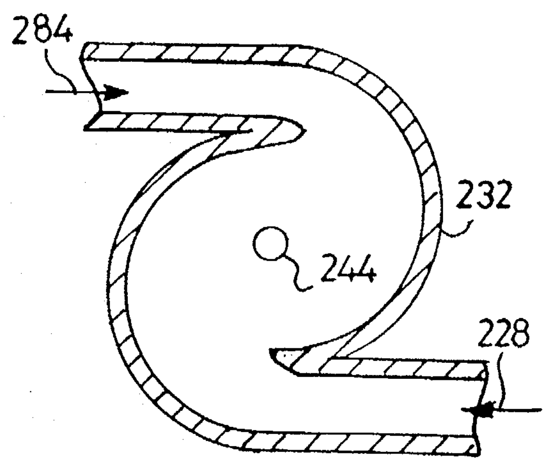

Fig. 18D

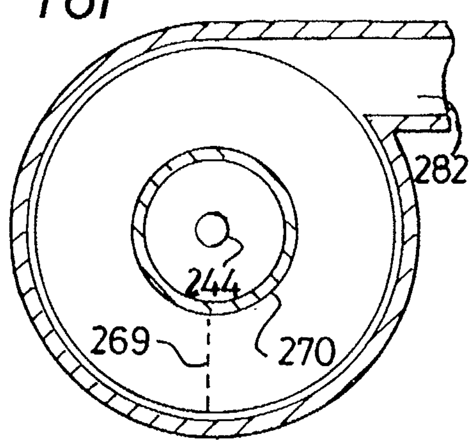

Fig. 18G

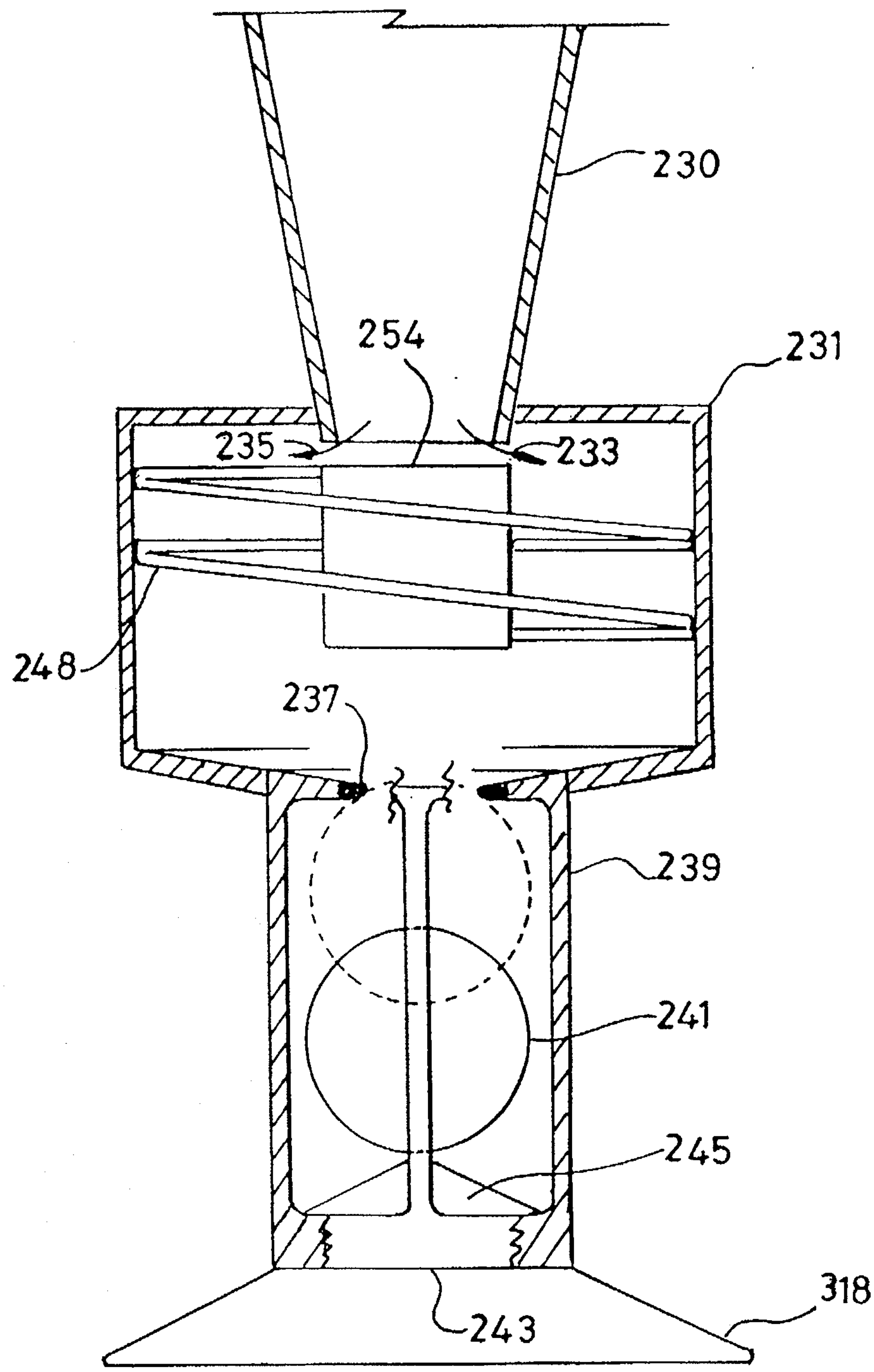

Fig. 19

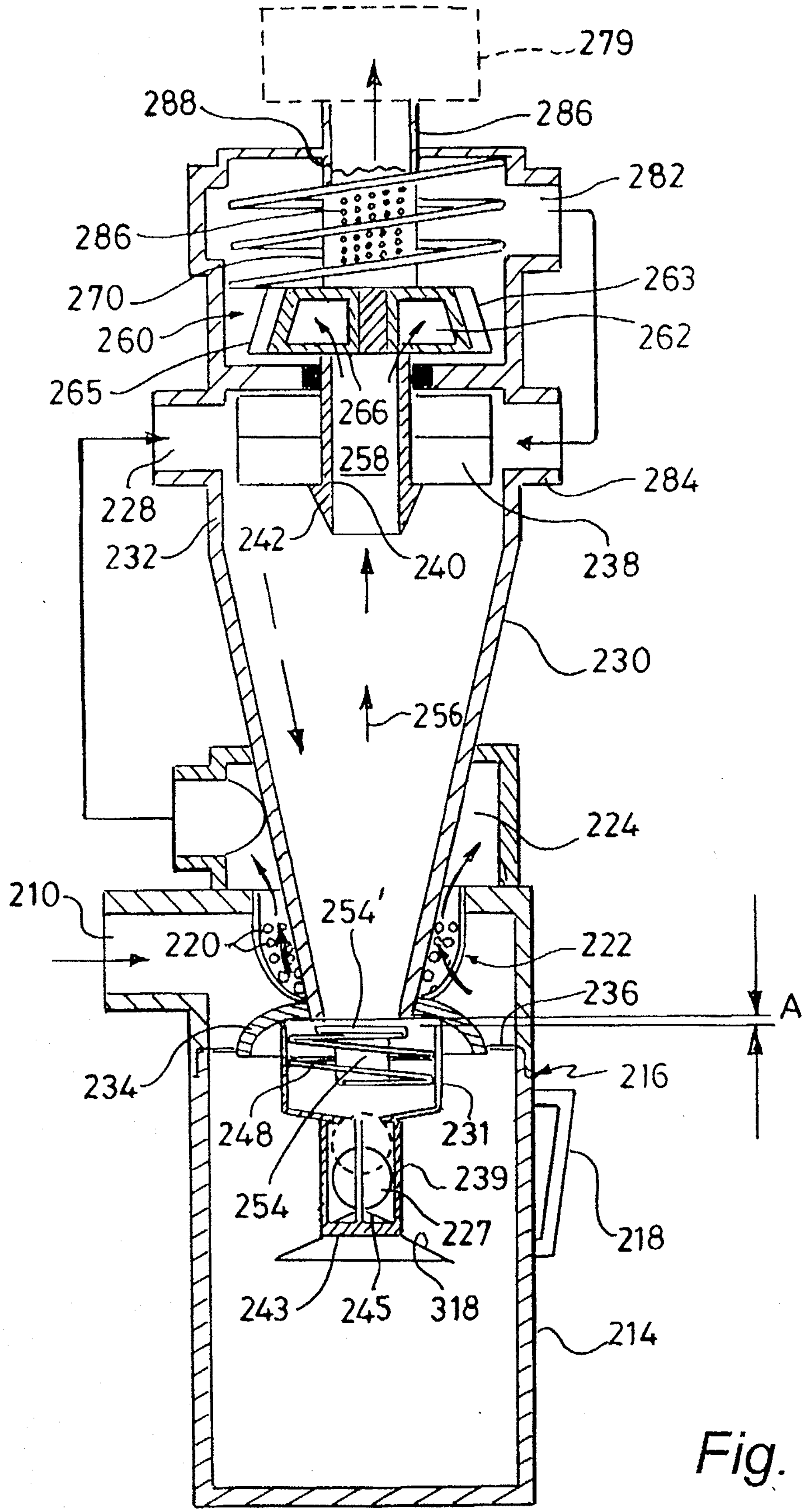
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Fig. 20

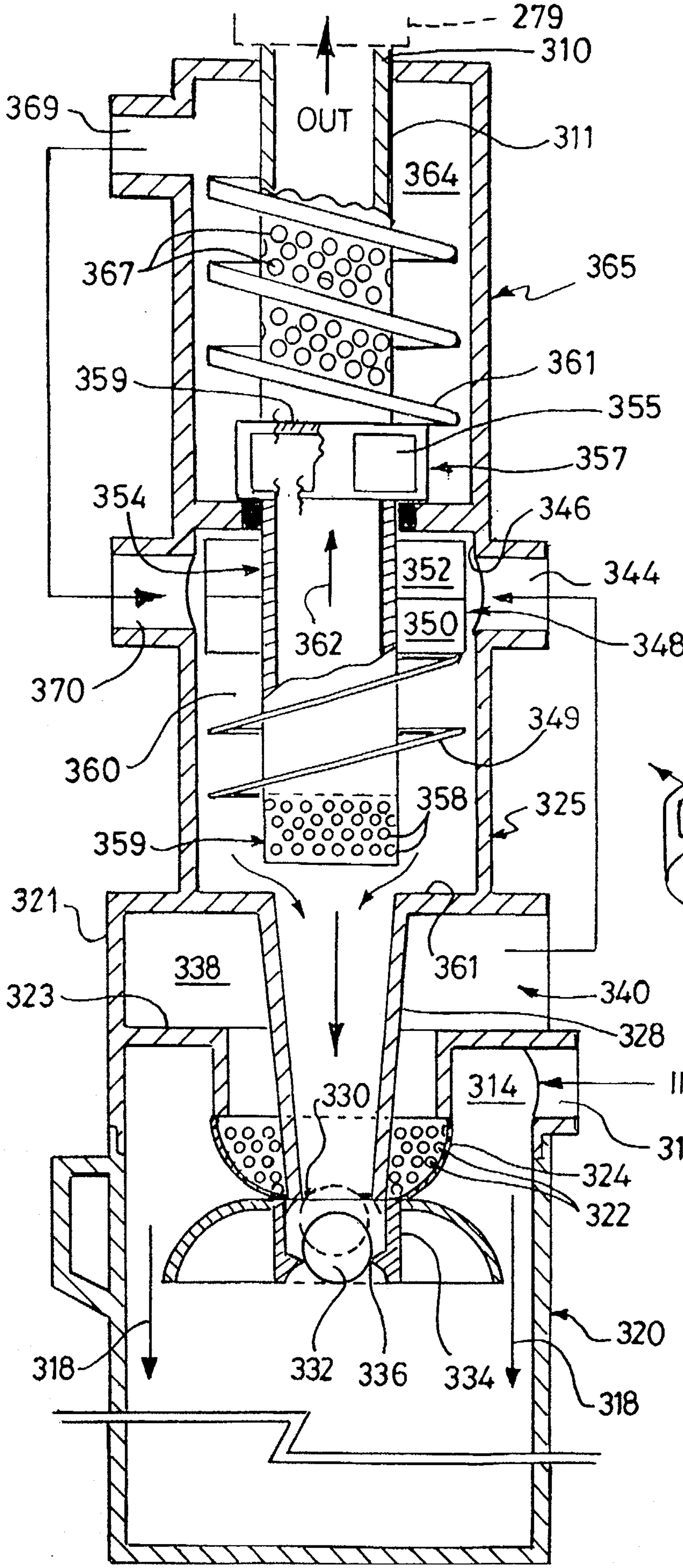

Fig. 21

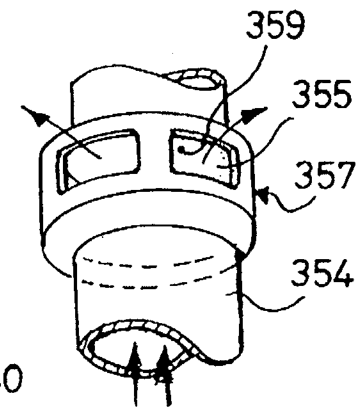

Fig. 21A

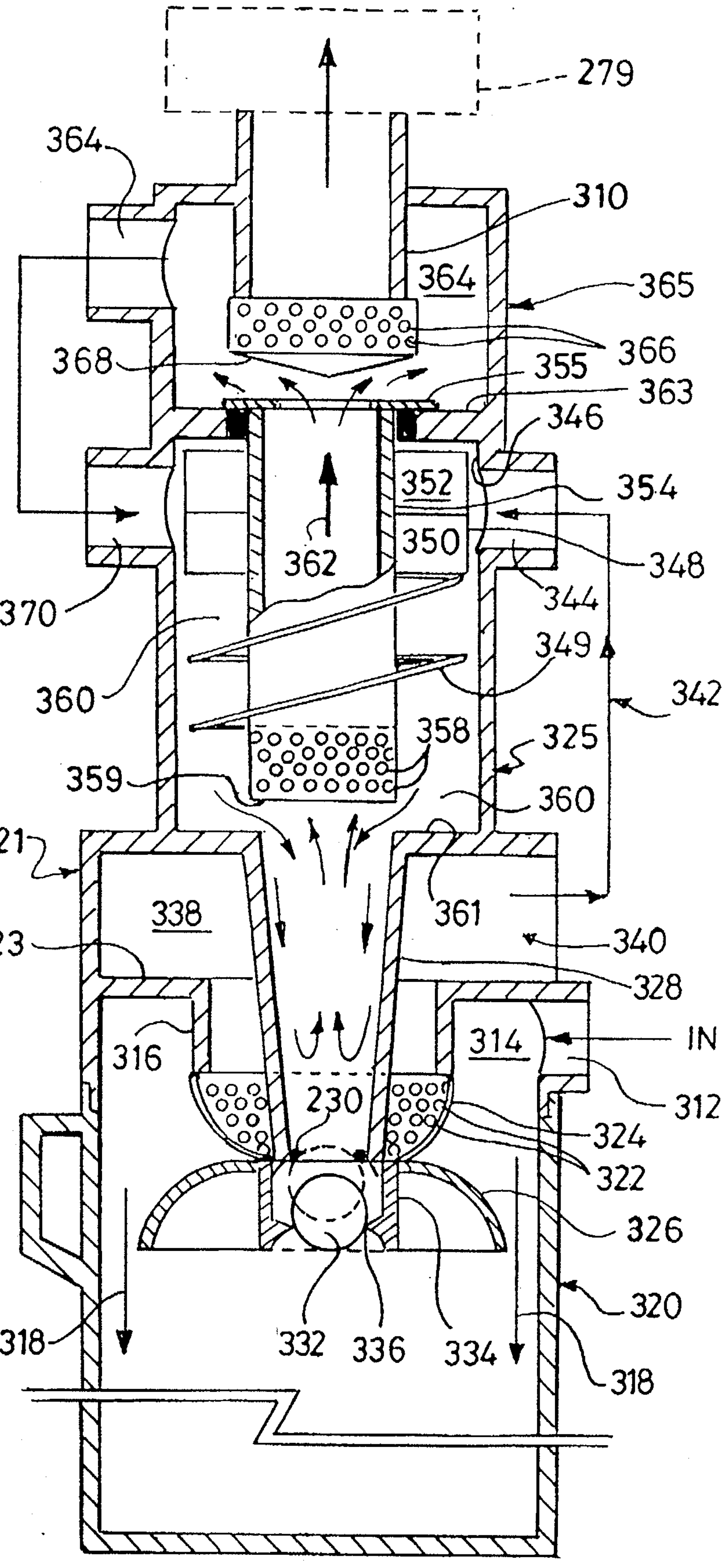
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Fig. 22

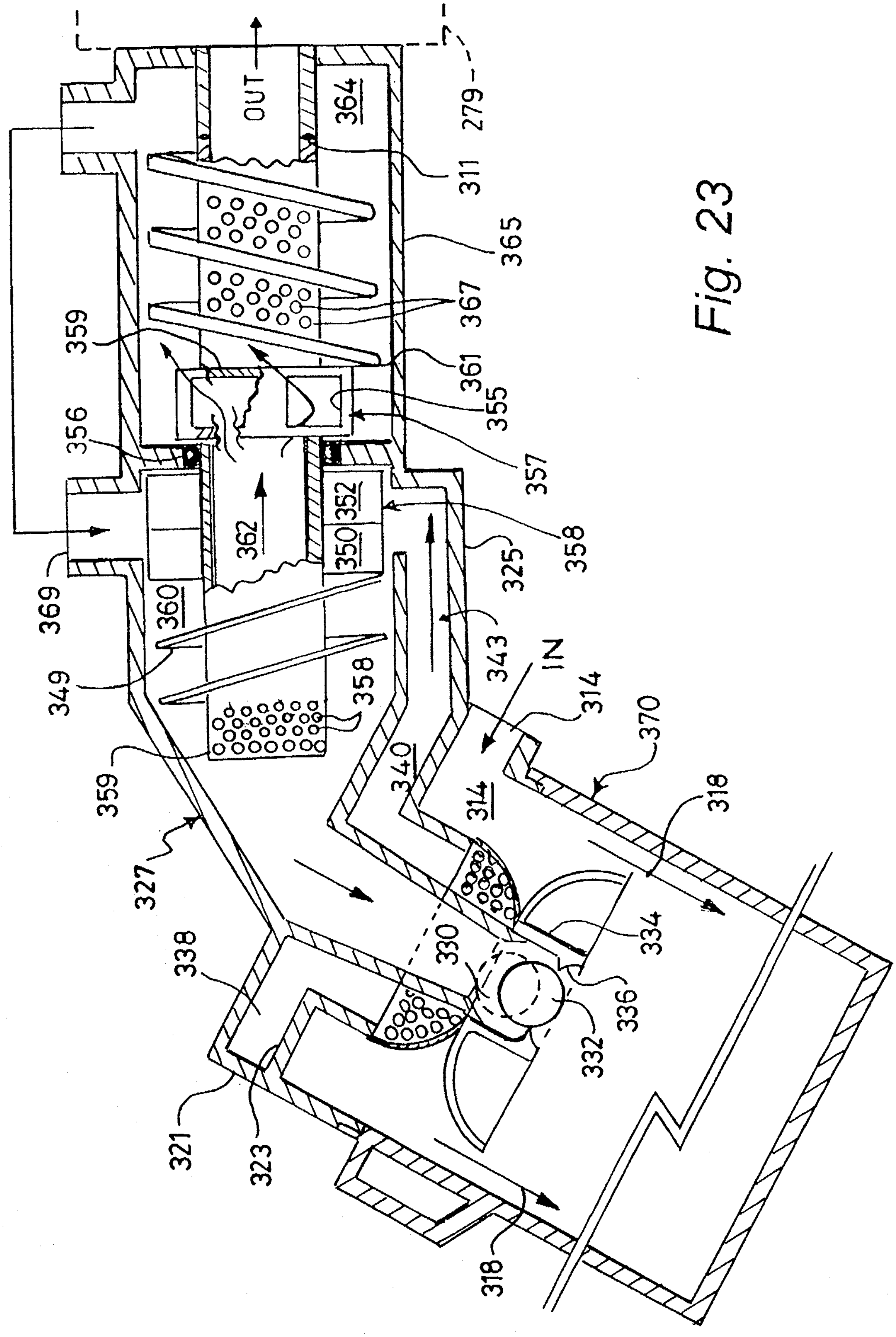
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Fig. 23

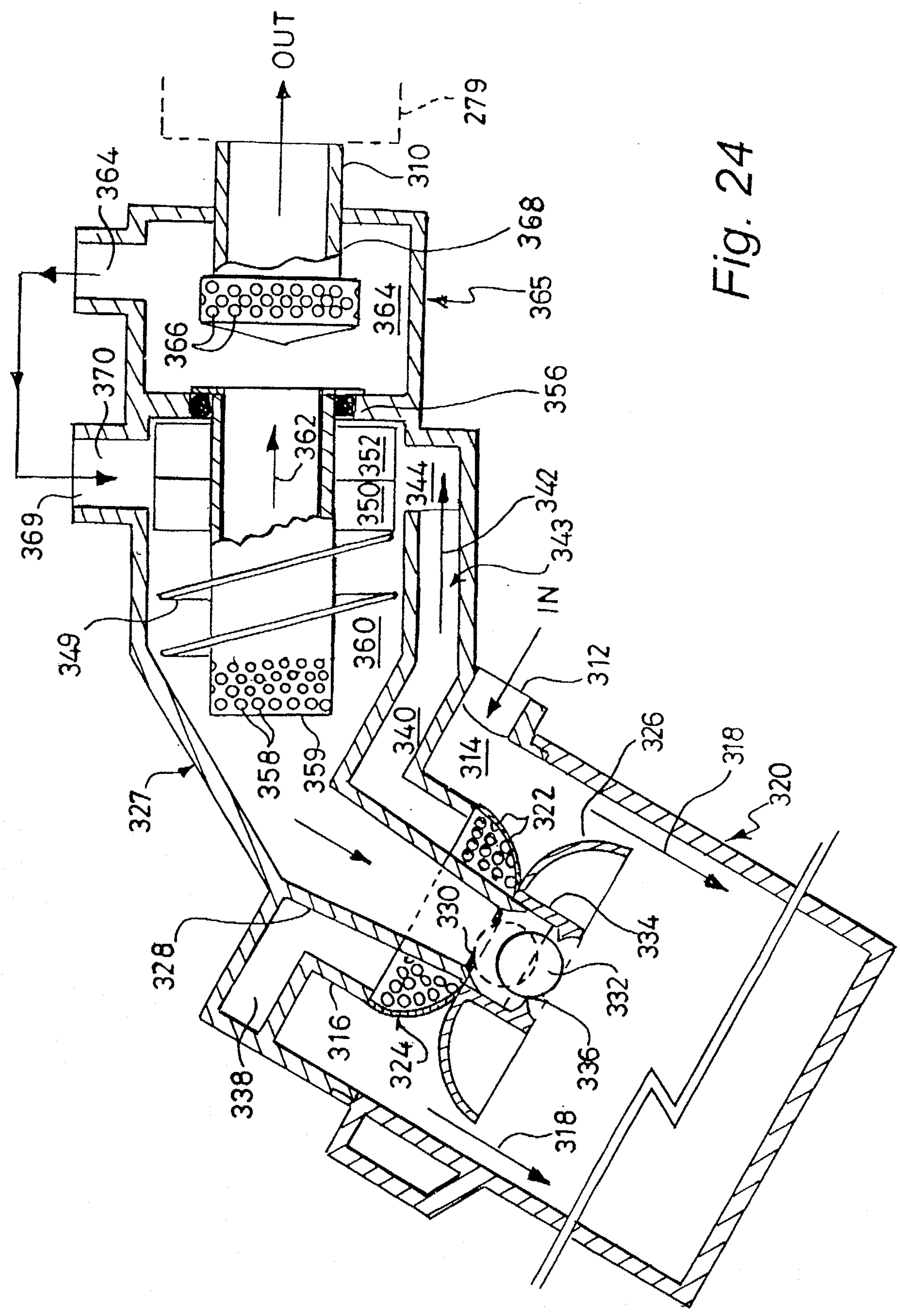
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Fig. 24

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C808/H

Title: Improved air-particle separator

Field of invention

This invention concerns a dust/particle separator in which a vacuum pump is used to set up one or more rotating cyclones for the purpose of separating dust and dirt particles from the airstream, the particles being retained in a dust collector and the cleaned air being returned to the atmosphere.

Background to the invention

It is known to separate dust and dirt particles from air by causing dust/dirt laden air to follow an annular path at high speed. Centrifugal forces cause the heavier than air content of the airflow to migrate to the outer regions of the annulus. The dust/dirt particles thrown out to the outer regions of the annulus can be collected in that they will tend to fall under gravity out of the airstream, and by collecting the air from the middle of the annulus, a high degree of particle/air separation can be achieved.

Object

It is an object of the invention to provide an improved cyclone separator, to provide a high separation efficiency, so that very small particles such as tobacco smoke particles, can be separated from air leaving a negligible quantity of particles in the final airflow.

Definition

In the following text and in the claims (except where the context does not admit) references to air are to be construed to mean any fluid whether gaseous or liquid and particles to

mean any particulate or fibre like material which has a greater density than that of the fluid.

Summary of the invention

According to the invention there is provided a multistage particle separator comprising at least two separation stages, in which particle-laden air is drawn through a succession of chambers in turn by suction applied to the last of the chambers, heavier than air particles being separated from the airstream in each chamber by centrifugal force, an conveyed to a collecting bin and particle depleted air being drawn from the chamber by suction, wherein an intermediate separation stage comprises:-

(1) a cylindrical chamber,

(2) a port through which air from an earlier stage enters the chamber,

(3) the port being arranged so that air entering the chamber does so generally tangentially,

(4) a hollow spindle extending centrally of the chamber and communicating with an opening in a closed end wall of the chamber, leading to the next separation chamber,

(5) a turbine mounted for rotation about the chamber axis and generally aligned with the port through which air enters the chamber, the incoming air causing the turbine to rotate,

(6) at least one opening at or near the end of the hollow spindle through which air can leave the chamber to pass along the interior of the spindle into the next separation stage, and

(7) a particle collecting region at the end of the chamber remote from the turbine.

The hollow spindle may be stationary so that the turbine rotates around the spindle.

Alternatively the turbine may be attached to the spindle so that the two rotate together, and a bearing allows for relative rotation between the spindle and the end wall of the chamber.

Preferably there are a plurality small openings in the wall of the spindle around one end thereof and the turbine is mounted at a position axially distant from the openings.

Typically the turbine containing region of the chamber is separated from the region of the chamber which communicates with the interior of the hollow spindle, by means of an annular baffle containing at least one opening therein through which air can pass from the one region to the other.

The baffle will normally be stationary relative to the turbine.

The rotating spindle imparts rotation to the air passing therethrough into the next chamber, so that the air is rotating as it leaves the interior of the spindle and enters the next chamber.

According to a preferred feature of the invention a second port is provided in the wall of the chamber circumferentially spaced from the first port, and a passage communicates between an exit from the next stage and the said second port, to allow particles separated from the air passing through the said next stage to be returned to the rotating airstream in the chamber for separation from the returning airstream before passing once again via the hollow spindle to the next stage.

According to another preferred feature of the invention a helical baffle extends radially from the spindle between the region containing the turbine and the region containing the end of the spindle through which air can leave the chamber, so that the rotating airflow leaving the turbine is constrained to follow a helical path thereby imparting an axial component of motion to particles entrained therein, to assist in separating them from the air as it changes direction to enter the spindle to pass to the next stage.

The helical baffle may be stationary relative to the chamber, or may rotate with the turbine.

The end of the spindle through which air enters the next stage, may extend into a chamber forming the next stage by means of a hollow cylindrical cap, the end of which is closed but

the cylindrical wall of which has at least one opening therein through which air can pass into the said next stage.

A cylindrical sleeve may concentrically surround the cap, having at least one aperture in alignment with the aperture in the cap, through which particles leaving the cap in a plane generally perpendicular to the axis of rotation, can pass into an annular region between the sleeve and the interior of the chamber, from which they are drawn by suction created by the rotating turbine at the second port in the wall of the turbine containing chamber.

The cap wall may include a plurality of windows equidistant therearound and the sleeve may be formed with a plurality of small openings or perforations in alignment with the rotating windows of the cap.

The sleeve may extend axially internally from one end to the other of the cylindrical chamber of the next stage.

The apertured region of the sleeve may only extend axially to the same extent as the cap extends axially into the next stage, but will normally extend over the full height of the chamber.

The internal wall of the turbine-containing chamber may become frusto-conical at the end of the chamber remote from the turbine, the frusto-conical region leading to a particle collecting region.

A valve may be located between the particle collecting region and another particle collecting region, in which particles recovered from the airstream flowing through another stage are stored.

An opening through which particle depleted air is drawn from the chamber of the next stage, may be located centrally of an end wall of the cylindrical chamber axially distant

from the end thereof through which air enters the chamber from the turbine-containing chamber.

In one embodiment of the invention in a cyclone separator in which air flow inducing means such as a fan or turbine driven by an electric motor generates a suction effect at an inlet to a cylindrical chamber such that air drawn into the chamber through the inlet enters the chamber in a generally tangential manner and is thereby caused to describe a circular path therearound, a turbine is mounted for rotation within the chamber about the chamber axis, the turbine largely occupying the circular cross-section within the chamber, the centre of the turbine comprises a hollow spindle through which air can pass axially from the first chamber into a second chamber which is otherwise separated from the first chamber so that air can only travel via the hollow spindle from the first to the second chamber, wherein suction induced inflow of air into the first chamber causes the turbine and hollow spindle to rotate at high speed, so as to cause the incoming air to rotate around the first chamber in the form of a cyclone.

The spindle may extend into the second chamber, so that air entering the second chamber via the hollow spindle will tend to be swirled around in a circular path as it enters the second chamber.

The suction induced flow of air may exit into the second chamber via an open end of the hollow spindle or the latter may extend axially into the second chamber and one or more openings may be provided in the wall of the spindle where it extends into the second chamber through which the air can pass. Radial fins may be provided between opening(s) in the spindle wall to further rotate the exiting airflow in the second chamber.

Preferably the rotation of the incoming airstream by the turbine rotating in the first chamber creates a vortex therein, and the first chamber is axially elongate, and of tapering circular internal cross-section and the turbine is located at the larger diameter end, so that after creating the vortex, a rotating mass of air will travel along the chamber in a direction away from the turbine, and while still rotating near the smaller diameter end of the

chamber, become inverted and create a secondary vortex which travels in the opposite direction axially and generally centrally of the first chamber, to enter an open end of the hollow spindle and after passing therethrough, exit into the second chamber.

The open end of the spindle which communicates with the second chamber may do so via a hollow shell of larger diameter than the spindle, the wall of the chamber being apertured, to allow air to pass therethrough into the second chamber. Radial fins may extend from the external wall of the shell between the apertures thereof.

The shell may be frusto-conical in shape with its axis coaxial with that of the spindle, and with the apertures in the frusto-conical wall thereof.

The spindle or an extension thereof may extend axially of the second chamber to provide a connection to a vacuum pump to induce the airflow into the first chamber, the interior of the spindle being blocked above the apertures in the wall thereof through which air exits into the second chamber therefrom, and the wall of the spindle above the blockage is also apertured, to allow air to re-enter the spindle interior to pass to the vacuum pump.

Preferably the spindle is in two parts, which are relatively rotatable, so as to permit the part of the spindle which passes through the second chamber wall to be stationary and the two parts are joined by a rotary seal.

A helix may extend from the wall of the rotatable part of the spindle beyond the internal blockage, so that air is forced to travel in a helical path as it rotates in and progresses axially of the second chamber.

An opening in the wall of the chamber beyond the helix communicates with a duct leading to a second air inlet to the first chamber so that air passing around the second chamber which is radially outermost of the general airstream, and in which (due to centrifugal forces acting thereon there will tend to be a high particle content), is returned together with the particle content via the duct, to the first chamber.

Preferably the helix is secured to the spindle in the second chamber, so as to rotate with the spindle and the spindle wall to which it is secured is apertured with small apertures to allow air following the helical path defined by the rotating helix, and near the spindle can enter the spindle through the apertures to pass to the vacuum pump.

The end of the spindle through which air would otherwise enter its hollow interior from the first chamber may be closed off, and a plurality of small apertures may be formed in the wall of the spindle near the closed end thereof, and air is forced to enter the spindle through the small apertures.

A second helix may be arranged around the spindle in the first chamber between the turbine and the apertured end thereof through which air enters the spindle from the first chamber, so that the rotating mass of air in the first chamber is constrained to follow a helical path as it rotates, so as to move axially therewithin, to further assist in establishing an axially progressing vortex and to further assist in forcing particle content thereof to the radially outer regions of the first chamber, to further assist in separating particles from the main mass of air.

The helix in the first chamber may be handed opposite to that in the second chamber and the direction of rotation established by the turbine, is chosen so as to effect the desired axial movement of air in each of the chambers, having regard to the handing of the two helixes.

Where the air enters the second chamber in a generally axial direction through a generally open end of the spindle, a conical surface is provided therein, axially spaced from the open end of the spindle, with the apex of the cone pointing towards the spindle, so that air entering the second chamber is deflected in a radial manner as it impinges on the conical surface, thereby accelerating the airflow in a generally radially outward sense, whereby particulate material in the airstream will tend to migrate to an outer circumferential region of the second chamber, and an air outlet from the second chamber is arranged centrally thereof, to the rear of the conical surface, so that air has to decelerate and reverse its

direction after leaving the conical surface, if it is to enter the outlet and pass to the vacuum pump. By doing so, particulate material in the airstream will tend to migrate to the outer wall of the chamber from where it will be entrained in the airstream leaving the second chamber to be returned to the first, and lighter generally particle-free air will tend to be collected by the central outlet and conveyed to the vacuum pump.

Thus in a preferred embodiment, the entrance to the interior of the hollow spindle from the first chamber may be via a plurality of small apertures in a region of the wall thereof beyond the end of the helix, and remote from the turbine, and the rotating mass of air creating the vortex travels away from the closed off end of the spindle, and after the vortex inversion returns thereto, where it is deflected radially outwardly by the closed end of the spindle and has to change direction and return in a radially inward sense before it can enter the apertures in the wall of the spindle, so that any particles in the air returning from the vortex inversion will also be accelerated radially, and being heavier than air will tend not to reverse direction and instead will tend to be entrained into the circulating airstream issuing from the rotating helix and forming the beginning of the descending vortex so that they will tend to be carried by that descending airstream once again to the vortex inversion region.

Where the closed, but apertured end of the spindle is rotating, this will tend to induce a rotation to the air flow returning from the descending vortex inversion, and this will further assist in accelerating particles outwardly to become once again entrained into the rotating descending vortex forming air from the helix.

Preferably the opening in the open end of the hollow spindle (through which air enters the second chamber), is arranged symmetrically relative to the conical surface, so that the apex of the cone is on the axis of the hollow spindle.

The size of the open end of the spindle opposite the conical surface may be selected so that at normal flow rates, the velocity of the air impinging on the conical surface is appropriate to achieve the radial displacement thereof.

Preferably the conical air-deflecting surface is carried by the end of a hollow tube extending axially of the second chamber, coaxially with the hollow spindle, and the wall of the hollow tube is apertured with small apertures through which the air can exit to the vacuum pump.

A separator constructed in accordance with the present invention is of particular value when it is necessary to remove very small particles such as tobacco smoke particles or droppings from bed-bugs and deliver clean air back to the environment, and is therefore of use in clinical applications, in hospitals, surgeries, nursing homes and the like.

In tests, a separator constructed in accordance with the invention achieved 99.952% separation using particles of less than 3 microns. In one test after handling air contaminated with 200g of 3 micron (or smaller) particles only 0.094g of particulate material was recovered from the exiting air stream, the remaining 199.906 grams having been retained in the collector.

If further separation is required, before passing to the vacuum pump, the air can be forced through a fine filter, which can be replaced periodically. However it will be seen that with particle separation efficiencies such as have been obtained without a filter, normally there will be little or no requirement for a filtration stage.

The invention will now be described by way of example with reference to the accompanying drawings, in which:

Figs 1 to 17 illustrate different air/particle separators, and include arrangements embodying the invention, and in which:

Fig 18 is a cross sectional elevation of a vacuum particle separator embodying the invention, and Fig 18A is a detail of the upper end of the device shown in Fig 18,

Figs 18B - 18G are scrap sections of the device of Fig 18,

Fig 19 shows a modification for part of the device shown in Fig 18,

Fig 20 is a similar view another separator embodying the invention,

Fig 21 is a similar view of another separator embodying the invention,

Fig 21A is a scrap detail of part of Fig 20, in perspective partly cut away,

Fig 22 is a view of another separator embodying the invention, similar to the view of Fig 18,

Fig 23 is a cross sectional view of an alternative configuration of separator which is based on the separator shown in Fig 20 but is constructed so as to be portable and can be carried in one hand, and

Fig 24 is a similar portable device such as shown in Fig 22, based on the separator of Fig 21.

In Fig 1 an electric motor driven fan or turbine 10 provides a source of suction at the upper end of passage 12 to draw air through the different stages of the apparatus, as will be described, from an inlet passage 14.

In the case of a domestic or commercial vacuum cleaner 14 will be connected to a hose (not shown) having a dust collecting head of known design (not shown) at its far end. The last part of the hose may in known manner be rigid.

In the case of a device for separating particles from air from apparatus such as in a laboratory or industrial or commercial environment, the inlet 14 will be connected to the enclosure from which dust/particle laden air is to be extracted.

A filter 16 (which may be removable for cleaning or replacement) may be located immediately prior to the suction source 10, although in some embodiments this may be dispensed with in view of the very high efficiency of such embodiments at removing particles from the incoming air.

The inlet passage 14 introduces air into the upper end 18 of a two part cylindrical chamber 20, 22, sealingly joined at 24 but separable to allow particles collected from the airstream to be emptied.

Particles are collected from a first separation step (which occurs within 20, 22) in the annular space 26 at the lower end of 22 formed by a central hollow frusto-conical housing 28 which extends centrally of 20, 22 to sealingly engage around a circular platform 30 upstanding from the flat, closed end 32 of 22. The space within 28 serves as a second particle-collecting region, for retaining particles separated from the airflow by a second separation step (to be described).

The upper end of 20 is closed at 34 but includes a central circular opening 36 through which a frusto-conical extension 38 of a second cylindrical chamber 40 can pass in a downward manner. An annular space 42 between the wall of the opening 36 and the extension 38 allows air to leave 20, 22 and pass into an annular manifold 44 from which it can pass via a passage (shown dotted at 46) to an inlet port 48 at the upper end of the chamber 40.

Inlet 48 introduces air into the interior of 40 in a tangential manner in a similar way to that in which 14 introduces air into the region at the upper end of 20, 22.

Centrally of 18, a collar 50 extends axially down onto 20, the interior of the collar communicating with the opening 36 in the end 34 of 20. The collar is generally cylindrical and terminates in a part hemispherical dome 52 which extends down to and surrounds the

frusto-conical extension 38, where it is sealingly joined at 54. A skirt 56 which is also generally part hemispherical and open at its lower end, extends from the join 54.

The dome 52 is perforated by a large number of very small holes 53. The skirt is non-perforated.

In operation, the incoming tangential rush of air through 18 sets up a rotating mass of air around 50 which can only exit via holes 53, which are axially displaced from the region into which the air is introduced. This causes the rotating mass of air to migrate axially as it rotates, so setting up a so-called vortex flow within 20, 22 and heavier than air particles will be flung towards the cylindrical wall of the chamber 20. The particles will axially migrate with the vortex and once in a downwardly spiralling trajectory will tend to continue in that manner axially down the chamber 20, 22 through the annular gap between the skirt 56 and the interior of 22.

Once the particles are below the skirt 56, there is little tendency for them to migrate back up the chamber, even if turbulence exists below the skirt, and they will tend to congregate in the annular region 26.

Thus although air entering at 18 may be laden with heavier than air particles (dust, hairs, grit and the like in the case of a vacuum cleaner), muck of these particles will be separated from the air before it passes through the openings 53 in the inverted dome structure 52. Therefore the air passing up through 42 and via 44, 46 and 48 into the upper end of the second separation stage, will be substantially depleted of particles, relative to that entering at 14.

As mentioned earlier, suction is applied to the upper end of passage 12, which is formed by a hollow generally cylindrical housing 58 which extends axially of the cylindrical chamber 40 to terminate near its lower end.

The lower end of housing 58 is closed at 60 but around that closed end, the wall of 58 is perforated with a large number of small holes 62, so that suction applied at 12 will cause air from within 40 to be sucked into the interior of 58 to pass axially therethrough in an upward sense.

This suction causes air to be drawn in through 48 from 44 so establishing the airflow through the chambers and passage 46, from inlet 14 to the suction device 10. The latter includes an outlet through which air, removed from the apparatus can exit to the atmosphere.

The external surface of the upper end of housing 58 is frusto-conical, and in combination with the tangential inflow of air, creates a rotating mass of air around the housing 58, which, since it must pass axially down the housing 40 before it can leave via holes 62, becomes a vortex which accelerates as it reaches the lower end of the cylindrical region of 40 due to a sudden frusto-conical reduction in the internal cross-section of 40, as denoted by 64. The acceleration increases the centrifugal forces on any heavier than air particles relative to the air molecules, so causing any such particles to carry on spiralling downwardly accelerating as they do due to the frusto-conical cross-section of the interior of extension 38 of the chamber 40.

The particles spiral down into the interior 66 of the housing 28, where they tend to remain.

If the airflow through 40 is high enough, the rotating and axially descending vortex of air may substantially bypass the openings 62 in the wall of 58 and continue to spiral downwards carrying the particles in the spiralling airstream. At some point the effect of the closed end 30 and the enlarging cross-section of housing 28 will cause the rotating mass of air to invert and begin ascending centrally of the downward spiral of air passing through 38 and 28, but in order to do so, the sudden deceleration and acceleration of the air molecules as they change direction, will in general be too sudden to allow heavier than air particles present in the airstream, to follow the same tortuous path as the air does, and such particles will become separated from the airstream and remain trapped in 28.

The two stages of separation so achieved, result in substantially all heavier than air particles remaining in 26 or 28 and largely particle-free air passing out through 12 and 10.

An improved separation can be achieved in the first stage by providing an annular flange 68 around the collar 50 at the junction between the perforated and unperforated wall sections. This serves to accelerate the rotating mass of air just before it reaches the perforated region 52, thereby forcing any heavier than air particles to migrate radially even further from the collar.

The effect is further enhanced by extending the periphery of the flange 68 in an axial manner to form a cylindrical lip 70 which extends in the direction of movement of the vortex in the chamber 20, 22.

Typically the diameter of the collar 50 is in the range of 5-8 cm and the radial extent of the flange will be if the order of 1cm and the lip can extend axially from the flange by a similar distance of the order of 1cm.

The separator may be used to separate particles from air which also contains liquid droplets such as water. The presence of the flange 68 and lip 70 reduces the risk of liquid droplets from being entrained in the air exiting via holes 52, since they, like any heavier than air particles, will be forced to adopt a high rotational speed to pass around flange 68 and will therefore be even further removed by centrifugal force from the inner regions of the chamber 20, 22.

Fig 2 illustrates an alternative 2-stage separator in which air flow is established in a similar way as in Fig 1 from inlet 14 to suction device 10, and the same reference numerals are employed to denote parts which are common to the two arrangements.

The main operational difference is the shortening of the length of housing 58 and the removal of the closed end 60 and apertures 62. The lower end of 58 is now open at 59.

Secondly the frusto-conical extension 38 of housing 40 now converges more sharply to define a small diameter neck 39 below which the extension reverses the frusto-conical configuration to form a trumpet-like end 41 which terminates in a cylindrical region 43. From below 43 (although not shown as such) the 2-bin configuration of Fig 1 may be employed, so that particles from 43 drop into a region 66 and those from around the skirt 56 into an annular region 26. As shown, a single bin or valve may be employed. Thus as shown, the lower end of 43 is formed as a cage 45 for a light weight ball 47, which when airflow is established, is drawn up to close off the lower end of 43 (as shown in dotted outline), the junction between 43 and 45 being of reduced diameter to form a valve seating. The lower end of 45 is partially obstructed to retain the ball.

A microswitch 72 is also shown in Fig 2 having an actuator arm 74, such that when particulate material in the chamber 20, 22 becomes high enough to lift the arm 74, the switch is operated and an alarm is initiated (audible or visible or both), (not shown) and/or power to the suction source 10 (e.g. current to the fan motor) is cut off to prevent further operation until the chamber 20, 22 has been emptied.

The level detecting switch may be fitted to the Fig 1 embodiment if desired, and one may be located in the space 66 and another in the space 26, or one in the space that, from experience, always fills up first. In general this will be the annular region 26.

Better separation in the chamber 40 is achieved if the housing 58 is extended and tapered to protrude into the upper end of 38 as shown at 58' in Fig 2A.

Fig 3 illustrates a further alternative 2-stage separator similar to Fig 1 (and to that end the same reference numerals have been employed as appropriate), in which a valve has been incorporated, as in Fig 2, but in which a different type of valve is shown from that shown in Fig 2. The valve is shown in more detail in Fig 4, and comprises a conical poppet 74 at the lower end of a spindle 76 at the upper end of which is a cup 78. A valve seating 80 retains an O-ring 82 against which the conical surface of the poppet 74 is forced, to close

the valve once airflow has been established through the apparatus. The spindle 76 extends through the poppet and is slidingly received in a guide 82 in a cross member 84 which extends across the open lower end of the housing 45. The cross member 84 and guide 82 are shown in the scrap view of Fig 4A.

Particles can pass down through the open end of tube 38 during operation, and remain above the poppet 74 until airflow ceases, whereupon the poppet drops and particles can fall past the conical surface of the poppet and around the cross member 84, into the common bin 22.

A spring (not shown) may be fitted between the conical surface 74 and the upper end of the enclosure 86, (or between the cup 78 and the end 86) so that as soon as airflow drops, the poppet valve opens under the action of the spring.

Fig 5 shows an arrangement that is similar to that of Fig 1 (and similar reference numerals have been employed throughout to denote similar components). Particles are collected in two bins as in Fig 1, so there is no need for a valve such as shown in Figs 2 to 4, although it is to be understood that mixing of the separated particles in bin 66 with air circulating in the frusto-conical vortex separation stage 38 is better prevented if a valve were to be provided between 38 and 66.

The main difference between Figs 5 and 1 is the provision of a helical baffle 88 around the central hollow member 58 in the second separation stage housed in chamber 40. This prevents air entering the chamber 40 from passing in a straight line to the openings 62 at the lower end of 58 and forces the airstream to continue to describe a circular route (albeit while progressing axially via the turns of the helix). This introduces centrifugal forces on the rotating air mass and thereby on heavier than air particles in that airstream, which will therefore migrate to the radially outer regions of the helical path followed by the airstream, and will be less likely to be caught up in the radially inward flow of air through the openings 62 to enable it to exit the chamber under the suction force from 10.

Fig 6 shows a variation on Fig 2 in which the lower end 60 of tube 58 (in the second stage) is closed off and the exit for the air from the chamber 40 is provided by a large number of small openings 62 in the wall of the tube, as provided in the embodiment shown in Figs 1 and 5. The arrangement benefits from the simplicity of the single particle collecting bin but therefore requires the addition of a valve as described in relation to Fig 2 and a level sensing microswitch 72 is also shown associated with the bin.

Fig 7 shows how the helical baffle of Fig 5 can be combined with the simplicity of the single bin and the improved second stage separation associated with the necked frusto-conical vortex separation chamber 38, 41 described in relation to Fig 2, to achieve a further overall improvement in particle separation for a given airflow and partciel size distribution. As before items which are common to earlier embodiments are identified by the same reference numerals as have been employed in earlier figures.

Figs 8 and 9 show how the designs of Figs 6 and 7 respectively can be modified to further improve separation in the second stage. In each case the stationary tube 58 is replaced by a rotatable tube 90 supported for rotation about its central axis by a bearing 92 in the upper end wall of the housing 40. Situated in general alignment with the air inlet 48 and fixed to the tube 90 is a two element turbine 94, 96 (although it is to be understood that a single turbine element such as 94 or 96 may be used in place of the two element arrangement). Where two elements are employed the one is mounted with its blades out of phase relative to those in the other, so as to effectively double the number of turbine blades on which the incoming airstream acts. This increases the speed of rotation.

Being attached to 90, the rotation of the turbine(s) causes 90 to rotate. Air entering the chamber is also forced to rotate with the turbine(s) before it can begin its passage down the interior of chamber 40 to exit via openings 62 in the wall of the tube 90. The rotation of the tube 90 will also help to keep air near the surface of the tube rotating in a similar manner, so that centrifugal forces will be active in heavier than air particles in the suction induced airflow through the chamber 40 as the latter migrates down the chamber.

This in turn assists in separating remaining in the airstream, from the air, which latter changes direction near the bottom of the chamber to exit, virtually particle-free, through the openings 62. Separated particles continue to rotate around the chamber close to the wall thereof, until they are accelerated by the radially reducing regions of 64 and 38 where they progress through via the valve arrangement into the common bin 22, as previously described.

The arrangement of Fig 9 differs from that of Fig 8 by the inclusion of the helical baffle 88 which is attached to the rotatable tube 90 similarly to the manner in which it is attached to the stationary tube 58. However, as the tube 90 rotates the helical baffle will similarly rotate and perform somewhat like a screw-conveyor and continue to rotate as well as axially move the incoming air and particles through the chamber 40.

In practice the separation efficiency of the Fig 9 embodiment is somewhat better than that of the Fig 8 embodiment.

Although not shown a level-sensing switch such as 72, 74 can also be employed in the arrangements shown in Figs 5, 6, 8 or 9.

Fig 8 also demonstrates diagrammatically how the necked form of vortex tube such as shown in Fig 2 may be used in place of the simple frusto-conical tube shown in Fig 1, and it is to be understood that either form of tube may be employed in the second stage of any of the different embodiments shown in the drawings.

A further improvement in separation efficiency, but which does not involve rotating parts, is shown in Fig 10. This embodiment incorporates a third separation stage in an extension 92 of the chamber 40. This arrangement is based on the arrangement shown in Fig 7 in which the central hollow tube 58 extends axially of the chamber 40 and carries a helical baffle 88. The upper end of the chamber 40 is closed by a wall 94 from which the tube 58 extends, the wall being apertured to communicate with the interior of the tube 58, so that

(as in Fig 7) air entering 58 can pass axially up the interior 12 to enter the suction producing device 10.

In the Fig 10 embodiment, the airflow leaving the upper end of the tube 58 now enters the chamber 96 (within the extension 92) and centrally of the chamber extends an elongate cylindrical member 98 the lower end of which is conically shaped at 100 with the apex of the cone pointing towards the incoming airflow from 58. The angle of the cone and the diameter of 98 are selected so as to cause the incoming air to be radially deflected so that any heavier than air particles in the airflow will tend to be displaced radially outwardly as well.

Around the member 98 is a helical baffle 102, which as shown is oppositely handed relative to the baffle 88.

The suction source 10 communicates with the upper end of chamber 96 via opening 104 so that air entering 96 from 58 in general has to pass up the helical path defined by the helical baffle 102, before it can exit via 104 to 10. In so doing, the rotation imparted to the ascending mass of air will cause heavier than air particles to migrate to the radially outer regions of the turns of the helix.

Surrounding the helix is a cylindrical shroud 106 having a large number of small openings 108 through which air and particles can pass into the annular region 110 between the shroud 106 and the inside surface of the wall of the chamber 92.

A return path for particle bearing air from this annular space is provided via a passage 112 to exit tangentially into the upper region of the chamber 40 generally opposite the tangential entrance 48 by which particle bearing air from the first stage enters, the airflow from 112 entering the rotating air flow (created by the inflow through 48) in the same direction as it is rotating in 40.

Particles which pass through the holes 108 will tend not to return through them, so that once separated from the rotating airstream in the helix within the shroud, the particles will tend to migrate via passage 112 to mix with the particles at the top of 40, where they will tend to be separated by the action of the vortex established in 40 as previously described.

The central member 98 is secured to the helix 102, which in turn is secured within the shroud 106, which in turn is secured at opposite ends to the top and bottom of the extension 92.

Figs 11, 12 and 13 show how turbine arrangements of Figs 8 and 9 can be modified to supply air and any remaining particles to a third stage separation unit which may be similar to what is shown in Fig 10, or may be a simple cavity 114 having a return path 112 as described in relation to Fig 10 with a central hollow deflecting collector 116 comprising a cylindrical shell 118 having a large number of small openings in the wall thereof and a conical closed lower end 120 which acts in the same way s the conical lower end 100 of the central member 98 in Fig 10.

In Figs 11-13 the perforated hemispherical shell 52 of the previous embodiments is now shown as a hollow frusto-conical shell 52' also formed with perforations 53 through which air and small particles can pass. In common with the hemispherical shell 52, the size of the openings formed by the perforations in the shell wall is selected so as to generally impede particles greater than a given size, to prevent them from passing into region 44. The larger particles are collected in the bin 22 (in the case of a single bin arrangement such as Fig 10) and in the outer region 26 of a 2 bin arrangement such as shown in Fig 1.

The shell 52' is shown cut-away to reveal the lower end of 38 in the same way as the hemispherical shell 52 in the earlier figures.

As shown in Fig 11, the lower part 122 of tubular member 58 may be separate from, so as not to rotate with, the upper end to which the turbine sections are attached, and may be

supported in place by a circular plate 124 having an opening 126 therein (see the scrap plan view of Fig 11A).

Fig 13 shows how a radial and circular motion can be imparted to the airflow entering 96 by a hollow cap 128 attached to the upper end of the tube 58, so as to rotate therewith.

The wall of the cap is apertured by means of a plurality of windows, such as shown at 130. As the cap spins around its axis air leaves the windows with radial and rotational motion in the direction in which the cap spins.

A cylindrical shroud 132 which is stationary and extends from top to bottom of the chamber 114 includes a large number of openings such as 134 through which particles and air can pass. In order to pass to the suction source 10, the air has to reverse direction beyond the shroud and return via other of the openings 134, to allow it to pass via the central opening in the upper end of chamber 114 and through passage 136 to suction source 10. In so doing any heavier than air particles will tend to be left outside the shroud to be gathered up in the airflow returning to the second stage via passage 112.

The use of the rotating cap 128 obviates the need for the shell 118 of Figs 11 and 12.

In the case of the Fig 11, 12 and 13 embodiments, the passage 112 and the ports by which it communicates with 114 and 40 are typically 32mm diameter, the angle of the cone 120 (where employed) is 160^0, the diameter of the holes 62 are in the range 2 - 2.5 mm, the gap between closed end 60 and the frusto-conical surface 64 is in the range 3mm to 18mm, and will depend on the diameter of the chamber 40, which typically lies in the range 65-80mm diameter. The gap referred to, and the necking of the tube 38 both resist back flow of the secondary vortex, and the diameter of the necked region is in the range 10mm to 18mm.

Although as shown in Fig 13 the holes 108 are shown as extending only over the lower part of the shroud 106, they may be (and preferably are) provided over most or all of the

wall of the shroud as depicted in Fig 10, so that any air which is sucked in an axial and radial sense, due to the suction at 136, will not tend to pass back through holes which register with the windows 130 in 128, but will tend to migrate inwardly through holes nearer the upper end of the shroud.

It is to be understood that the two-bin collector of Fig 1 (with or without a valve or other device resisting mixing of particles in the inner bin with air in the descending or ascending vortex in 38) may be employed in conjunction with any of the second and/or third stage arrangements shown in Figs 2 to 13.

It is also to be understood that a particle level detector and switch such as shown in Fig 2 may be employed in any of the arrangements shown in any of the Figs (including Fig 1) for the purpose of at least alerting the user to the fact that the bin (or one of two bins) is full and needs to be emptied - if not also interrupting the power to the suction source.

It is also to be understood that the single bin and valve arrangement of Fig 2 may be employed with any of the second and/or third stage separators shown in any of the figures in the drawings.

The arrangements shown in the figures hitherto all relate to an upright vacuum powered air/particle separator, such as an upright vacuum cleaner. To reduce the overall height of such a device one or more of the 2nd and 3rd stages may be angled relative to the first stage such as shown in Figs 14 to 17. In all other regards they operate in just the same way as if the stages were mounted vertically one above the other. The opportunity has been taken to illustrate further variations on the make up of the second and third stages previously shown in earlier figures.

Fig 14 corresponds to the Fig 2 arrangement, as modified by Fig 2A, in which the end of the vortex tube 58 is bent around so as to enter the open end of the frusto-conical region 38.

Fig 15 corresponds to Fig 11 in so far as air and particles remaining near the wall of the third chamber will tend to return via a path 112 due to the depression at the other end of path 112 caused by the rotating mass of air in the second stage. However Fig 15 shows that the turbine of Fig 11 may be omitted. Fig 16 corresponds to Fig 12 in that a helix is provided in the second stage (albeit stationary) and no turbine is provided in the second stage.

In Figs 14 to 16 the perforated shell 52" is shown of cylindrical configuration as distinct from the hemispherical and frusto-conical configurations in earlier figures.

Figs 17 and 17A correspond to Figs 13 and 13A.

Although the valve shown in each of Figs 2 and 6 to 17 is a ball valve, it may be replaced by the valve shown in Figs 3 and 4, and this may be to advantage in the case of embodiments such as shown in Figs 14 - 17 in that the movement of the valve closure member may no longer be 100% vertical and a spring which is compressed when the valve is closed, to assist in opening the valve when airflow ceases, may be desirable.

It is of course to be understood that a spring may be incorporated in the ball valve design (although not shown) to make the opening of such a valve more positive, whether in a vertically arranged apparatus or in a non-vertical arrangement as shown in Figs 14 to 17.

In Figs 14 to 17 the reference numerals identify items in common with earlier figures.

Fig 18 illustrates a cyclone vacuum separator which includes a turbine and comprises a suction inlet 210 which can be connected to an enclosure or to a hose and dust collecting wand, for removing dust/particles from the enclosure, or from the environs of the end of the hose or wand.

The suction inlet enters tangentially a cylindrical enclosure generally designated 212 and the upper end of a dust and dirt collecting drum 214. The lower part 214 is typically a

push-bit at 216 to the upper region 212 and includes a handle 218. When full, the drum 214 is detatched from the upper end 212, and emptied. The push-fit must provide a good sealing joint between 212 and 214 or a separate ring seal must be included.

The tangential entrance of the air stream causes the incoming air to circulate around the interior of the cylindrical region 212 and because of the higher mass of dust particles relative to air particles, the dust and dirt entrained in the air stream tends to migrate to the outer ends of the rotating air stream and fall into the drum 214 whilst relatively dust free air tends to spiral inwardly to eventually pass through the plurality of openings such as 220 in the hemispherical dish generally designated 222 located axially centrally of the cylindrical region 212.

After passing through the holes 220, the air rises into the upper cylindrical cavity 224 from which it exits via port 226 and is conveyed to the inlet port 28 at the upper end of a conical chamber 230 in which the second stage of separation occurs.

The upper end 232 of the conical housing 230 is itself cylindrical and the entrance 228 communicates tangentially with that cylindrical region in the same way as inlet 210 communicates with the cylindrical region 212.

It will be appreciated that as the height of dust and particles in the drum 214 begins to rise, there could be a tendency for the rotating air stream in the region 12 to draw dust and particles from the heap in the bottom of drum 214, back into the air stream from which they have been separated by the centrifugal force in the upper cylindrical region 212. To reduce this tendency, a hemispherical baffle 234 is provided so that only a narrow annular region 236 exists through which the particles and dust can fall from the rotating air stream in the region 212, into the drum 214. The baffle 234 serves to separate the rotating air stream in the region 212 from the dust and particle content of the drum 214, and reduces the risk of the dust and particles in 214 becoming entrained in the rotating air stream in 212.

The hemispherical surface 222 merges into the oppositely curved hemispherical surface of the baffle 234 where they are both joined to the lower end of the conical housing 230.

The latter therefore provides the central support for the baffle 234 and for the hemispherical surface 222 containing the exit apertures 220.

It will be appreciated that the presence of the lower end of the conical housing 230 penetrates and therefore renders incomplete, the two hemispherical surfaces 222 and 234.

Within the upper cylindrical region 232 is located a turbine shown designated 238 carried by a central hollow axle 240, the lower end of which is formed with a frusto-conical surface 242 which serves as a cyclone starter for the conical chamber 230.

Air entering the cylindrical region 232 via port 228 causes the turbine to rotate and the rotating air stream set up by the tangential entrance of port 228 into the cylindrical region 232 causes a downwardly spiralling cyclone in manner known per se. Dust and particles entrained in the spiralling air stream tend to be deposited at the lower end of the conical chamber 230 where they pass through a circular opening 44 into a secondary collecting bin 246 after first circulating around a helical baffle 48 at the upper end of the secondary bin 246.

The latter is also conical in configuration and is complementary to the conical housing 230. The interior of the conical secondary bin 250 serves to collect dust and particles separated by the inversion of the vortex at the lower end of the frusto-conical chamber 230, but it will be seen that the wall of the secondary bin 246 separates the interior 250 from the annular region 252 within which the separated dust and particle content from the primary air stream bin 212, are collected.

The centre of the helix 248 presents a flat circular end 254 a short distance below the cylindrical passage 244 leading from the end of the conical chamber 230, and typically the diameter of 244 is of the order of 10mm and the distance between the open end of 244 and

the plate 254 is of the order of a few millimetres. The downwardly ascending spiral of air within 230, reverses near the lower end 230 to form an upward spiralling central vortex (not shown) which moves in the general direction of the arrow 256 to pass into and through the hollow interior 258 of the axle 240, and to enter a cylindrical region above the cylindrical region 232 housing the turbine 238. The passage from 258 into 260 is through windows such as 262 in a frusto-conical shaped spinner 263 which is mounted on the axle 240 so as to rotate with the turbine 238. Upper and lower walls of the spinner 264 and 266 respectively are closed, so that air passing into the central region of the spinner 263 can only exit through the windows such as 262. Radially extending flanges such as 265 located between the windows, impart rotation to the exiting air stream as it enters cylindrical region 260, and the air spirals upwardly through the chamber 260 further assisted by a rotating helix 268 mounted on a second horizontal axle 270 which rotates with the spinner 263.

Air from 258 cannot pass axially into the interior 278 of the second hollow axle 270, but has to pass through the windows 262 and after circulating around chamber 260, can either pass into the interior 278 of the upper axle 270 via holes such as 280 in the wall of the upper axle or can leave the chamber 260 via exit 282 to re-enter the air stream below the spinner 263 via an inlet port 284 located in the cylindrical region 232 at the upper end of the conical cyclone chamber 230. The port 284, like entrance port 228, merges with the cylindrical region 232 in a tangential sense so that incoming air from 282 will circulate around the cylindrical region 232 and further assist in rotating the turbine 238 and will merge with the incoming air stream via 228, to traverse the conical chamber 230 once again before proceeding up the centre of 230 as previously described and enter the region 258.

Because of the way in which air is collected from the upper chamber 260 via the port 282, any air leaving via port 282 will preferentially include any dust or heavier than air particles relative to that near the centre of chamber 260 and therefore the return path to 284 will tend to include dust and particles which have not been separated by the final separation

stage in the region 260, whereas air entering the region 278 via the holes 280 will tend to be free of dust and particles.

Although not shown in detail, 278 communicates with a vacuum pump or other suction device 279, (such as a fan or turbine driven by an electric motor or the like), the action of which is to draw air in the direction of the arrow 274 from the apparatus shown in the rest of the drawing. It is this suction which establishes the incoming air stream at 210 and the general flow of air through the apparatus as previously described.

It has been found that apparatus such as shown in Figure 18 can operate at a very high efficiency of separation so that very little dust and particle content is left in the air flow leaving 278, and it has been found possible to dispense with the filter which is normally located at such a position in the vacuum cleaning apparatus just prior to the vacuum pump (fan or turbine) 279. The presence of any such filter substantially reduces the air flow and therefore suction effect created by the fan and/or turbine, and by not having to include such a filter, the air flow through the apparatus, and therefore the air speeds within the various rotating air streams and cyclone is increased, and the separation efficiency enhanced.

Since the hollow axle 270 rotates with the spinner 263, and it is not desirable for the wall 286 to rotate, a rotational seal 288 is required between the rotating portion 270 and the stationary portion 286. This may for example comprise complementary chamfered end surfaces between the two cylindrical walls with bearing material at 290 and 292 as shown in Figure 18A.

Although described as a single turbine, 238 may be formed from two similar turbine blade assemblies each occupying half the axial length of the turbine 238 as shown, and each secured on the axle 240 with the blades of one turbine staggered by half the pitch of the blades of the other turbine so as to effectively double the number of blades of the turbine and therefore increase its efficiency.

Figure 18B is a cross-section view through the cylindrical region 212 of Figure 18, and shows the tangential inlet 210 and the cylindrical form of the wall of the conical chamber 230 where it is sectioned, the small orifice at the lower end of the chamber 230, and the intermediate cylindrical outline of the wall 222 where the hemispherical surface 222 is cut by the cross-section.

Figure 18C is a cross-section through CC in Figure 18, and shows how the exit port 226 communicates with the cylindrical region 224 and further assists in keeping the air mass rotating as it exits into the region 224 by virtue of the tangential exit 226 therefrom.

Figure 18D is a cross-section on DD in Figure 18, and shows one arrangement of inlet port 228 and return port 284 in the region of the turbine 238.

Figure 18E is similar to Figure 18D, but shows alternate positions for ports 228 and 284 if desired.

The important criterion is that a rotating air mass in 232 set up as air enters at 228 will tend to swirl past port 284 and continue in this circular motion around 232, rather than enter 284. In the same way, air re-introduced into 232 via 284 will likewise be swept into the rotating airstream induced by air entering by 228, and there will be no tendency for the air to enter the port 228 during its rotational movement within 232.

For clarity, the turbine blades are not shown in Figures 18D and 18E, but instead the turbine is shown in Figure 18F. This shows hollow axle 240, central region 258 and eight curved turbine blades of which one is designated 241. As shown in Figure 18F, the turbine is viewed from above, since it will be appreciated that air entering region 232 should be directed against the surface 243 of the blade 241 (and the corresponding surface of each of the other blades) to induce rotation of the turbine.

Where two turbines are mounted on the axle 240, each is of the same configuration as shown in Figure 18F, but of half the axial depth of 328, so that the two will fit within the

same axial space, and are mounted so that when viewed axially, the blades of one turbine will be seen to occupy the spaces between the blades of the other. The blades of the second turbine if fitted, are shown in dotted outline in Figure 18F, and one of these is denoted by reference numeral 245.

Figure 18G is a cross-section through Figure 18 on line GG and shows the exit port 282 communicating tangentially with the cylindrical interior 260 and the cylindrical wall 270 of the hollow axle on which the helix 268 is mounted, the upper end of which is shown at 269.

It will be appreciated that the helix is a relatively close fit within the cylindrical housing defining the chamber 260.

Although not shown in the drawing, it has been found advantageous for the openings 280 in the wall 270 to start a short distance after the beginning of the helix at the lower end 270 and to terminate a short distance prior to the end of the last turn of the helix at the upper end of 270.

Typically the apertures 280 are circular and have a diameter of 1.7mm and approximately 1200 such holes are formed in the wall 270.

Typically the helix has an angle in the range 2 to 10°, typically 4°.

Figure 19 shows a modification to the lower end of the frusto-conical separation tube 230. The lower end terminates in chamber 231 instead of the cylindrical nozzle 244 of Figure 18, and within the housing 231 is located a helix corresponding to item 248 of Figure 18.

The gap between the upper surface 254 of the central region of the helix 240 and the lower end of the conical tube 230 is selected so as to achieve the desired objectives, namely free ingress of dust and particles in the direction of the arrows 233 and 235 into the helix and

thereafter into the lower region of the chamber 231, but minimal transfer of dust or particles in the reverse direction.

A cage 239 extends below the chamber 231 arranged symmetrically relative to the valve seat formed by the seal 237. Within the cage is a ball 241 which can cooperate with the valve seat seal 237 to close the opening into the chamber 231. The density of the ball is selected so that a rising air stream passing in an upward sense through the cage into the chamber 231 will cause the ball to lift and become a valve closure member as it seals against the lip seal 237.

The cage includes a base 243 the internal upper face of which is formed as a shallow pyramid at 245 to space the ball from the base of the cage when air flow is zero, and the ball can fall under gravity to leave the opening defined by the valve seat seal 237, open.

When the Figure 18 apparatus is modified as shown in Figure 19, the secondary bin 246 can be dispensed with. The whole of the drum 214 is now available for storing any dust and particles collected by the separation process whether in the primary separation stage in the cylindrical region 212 or in the secondary stage caused by the reverse cyclone effect within the conical housing 230.

The Figure 19 arrangement enables this since as soon as air flow is established in the apparatus, some of the air entering at 210 will divert into the lower part of the drum 214 and rise up through the cage 239, the opening defined by the valve seat 237, through the helix 48 and into the conical housing 230. However air flow will lift the ball 241 into engagement with the seal 237 (as shown in dotted outline) to close the opening at the lower end of the chamber 231 and thereafter the apparatus will operate substantially as described with reference to Figure 18. The chief difference is that particles and dust separated by the vortex inversion in the frusto-conical housing 230 will now leave in the direction of the arrows 233 and 235 and after traversing the helix 248 remain in the small chamber 231. When the air flow ceases as at the end of a cleaning session, the ball 241 immediately drops to its lower position from the one shown in dotted outline in Figure 19, and any dust

and dirt particles in the chamber 231 will fall through the opening around the ball, and out through the openings in the cage 239, to join the rest of the dust, dirt particles collected within the main drum 214.

Whenever the apparatus is powered up again, airflow is once again established, and the process is repeated, with the initial closing of the opening by the engagement of the ball 241 with the seal 237, and the collection of dust and dirt particles in chamber 231. When the apparatus is again powered down, dust and dirt particles collected in 231 will again leave the chamber via the now open valve seating and join the rest of the dust and dirt particles in the main drum 214.

The ball 241 and seal 237 therefore represent a one-way valve which, in combination with the helix 248, prevents dust and dirt particles from entering the lower end of the conical housing 230 when airflow is established. This effectively creates a secondary bin for the dust and particles collected from the secondary separation which occurs in the conical housing 230, until it is opportune to mix the dirt particles and dust collected therein with those in the remainder of the drum 214.

Fig 20 shows the device of Fig 18 modified to include the vacuum operated valve closure device of Fig 19 fitted at the lower end of the frusto conical chamber 230. In other regards the arrangement is similar to the Fig 18 embodiment except that the particle/dust/dirt collecting vessel 214 is not divided internally into two sections as in Fig 18 and there is therefore a greater volume for storing material separated by the cyclone/vortex separation functions of the device, before emptying is called for. The same reference numerals have been employed in Fig 20 as have been used to denote the similar parts in Figs 18 and 19.

The only significant variation lies in the provision of a plate 254' at the upper end of the central core 254 carrying the helix 248 within the chamber 231 of Fig 19. The area and spacing of the surface of the upper end of the core 254 affects the vortex inversion in 230 and a fine tuning of the operation of the system can be achieved by using a plate 254' of size and thickness which may be found by experiment.

Fig 21 shows a further modification of the vacuum operated valve assembly in which the upper surface of the ball closure serves as the cyclone inversion device in place of a plate such as 254' as in Fig 20.

In Fig 21 a vacuum pump 279 is attached to outlet 310 and dust-laden air enters inlet 312. The cylindrical interior of the chamber 314 and the central hollow cylindrical housing 316 cause the incoming airflow to rotate around the chamber at high speed in the form of a cyclone which in known manner tends to cause the particle content to migrate to the outer regions and as it slows, to fall in the direction of the arrows 318 into a dust collector bin 320.

The rotating air stream can only leave chamber 314 via the apertures 322 in the domed surface 324 which extends below the cylindrical housing 316 and merges with a convexly curved shield 326 which tends to trap dust and dirt particles in the lower region of the collector 320.

Centrally and internally of the housing 316 is a frusto conical tube 328 the lower, smaller diameter end of which forms a valve seating 330 for a ball 332 which is held captive by, but is free to move within, a cage 334. The weight of the ball 332 is such that when the airflow ceases, the ball drops to the bottom of the cage and closes off a lower opening 336, but is light enough to rise under the action of suction induced airflow during operation of the separator, to sealingly engage the valve seat 330 and close off the lower end of the tube 328.

Air passing through the holes 322 rises into a cylindrical chamber 338 in an upper part 321 of the bin 320 which is separated from the latter by a wall 323. Air can leave chamber 338 via outlet 340 and pass though a duct (not shown) in the direction of arrows 342 into a first inlet 344 of an upper cylindrical chamber 346 at the upper end of a cylindrical housing 325 extending axially from the housing 321. Mounted for rotation about a vertical axis in 346 is a turbine 348, which as shown includes two sections 350, 352 one above the

other to increase its efficiency. The turbine is carried by a hollow cylindrical shaft 354 carried in a bearing assembly 356 and below the turbine 348 a single start helix 349 extends from the wall of the shaft 354. The closed lower end of the shaft is apertured as at 358 and air which has been rotated by the turbine and forced to traverse the helical path determined by the rotating helix forms a descending cyclone or vortex in chamber 360 which traverses the narrowing bore of the conical tube 328. Dust and other particles in the air stream are separated under gravity as the vortex is inverted and the rotating airflow migrates back up the centre of the tube 328 to exit the chamber 360 through apertures 358 in the lower end 359 of the hollow shaft 354.

Rising up through the interior of shaft 354, in the direction of arrow 362, and still rotating, the air enters an upper chamber 364 in an upper cylindrical housing 365 which extends axially above the housing 325, via openings such as 355 in a cylindrical enlargement 357 in the shaft 354.

A further helix 361 is carried by the upper part of 354 (above 357) and since 354 and 357 are joined, the helix 361 rotates with 354 as does helix 349 carried by the lower end of 354. The two helixes 349 and 361 are oppositely handed so that rotation of 354 causes air/particles in 365 to describe a rising helical path in 365.

The interior of 357 is hollow and communicates with the hollow interior of 354, below 357, but an internal wall 359 divides the interior of 357 from the interior of 354 above 357.

Dust/particle laden air will tend to be spun radially outwardly away from 354 through the outlet 369, while clean dust/particle-free air will tend to rotate closer to 354 in 364 and will exit through the apertures 367 in the wall of 354 between the turns of the helix 361.

A stationary tube 310 through which air can pass to the vacuum pump 279 is sealed to the upper end of 354 to allow relative rotation by a rotatable seal 311.

Dust/particle-laden air leaving via 369 will be returned via another duct (not shown) to the second inlet 370 of the chamber 346, where it is immediately entrained with the rotating air stream generated by the rotating turbine 348, and is caused to traverse the separation chamber 360 and tube 328 as a descending and rising spiralling cyclone as before, whereby residual dust/particles in the air are stripped out by the action of the abrupt change of direction at the bottom of tube 328, as previously described.

In this way the particle/dust laden airflow circulating between chamber 364 and chamber 346 is continually being stripped of particle/dust content.

Fig 21A shows in more detail the enlargement 357 between the upper and lower parts of hollow shaft 354, two of the openings (one of which is denoted by reference numeral 355) through which air/particles can exit (as shown by the arrows in Fig 20A) from the interior of the lower part of 354. Also visible through the openings, such as 355, is the internal baffle plate 359 serving to divide the interior of the lower part of 354 from the interior of the upper part thereof.

Very high separation efficiencies have been obtained using an arrangement such as is shown in Fig 21.

Fig 22 is similar to the embodiment of Fig 21 except for the treatment of the rising airflow in the chamber 364.

In the Fig 22 embodiment this part of the Fig 21 device is somewhat simplified in that hollow shaft 354 terminates in a flange 355 above the bearing 356. The centre of the flange is apertured so that air rising up 354 can escape into chamber 364 where it is deflected radially on impact with a downwardly facing conical face 368 of the lower end of the stationary hollow tube 310, which serves as the air outlet to the vacuum pump 279. Apertures 366 in the wall of 310, near the lower end 368, allow relatively dust/particle-free air from the central region of the airflow around 310, to pass to the vacuum pump 279 via the tube 310.

Dust/particle-laden air will tend to be spun radially outwardly around 310, and will exit through the outlet 364, from where it is returned via another duct (not shown) to the second inlet 370 of the chamber 346. Here it is immediately entrained with the rotating air stream generated by the rotating turbine 348 and is caused to traverse the separation chamber 360 and tube 328 as a descending and rising cyclone as before, whereby residual dust/particles in the air are stripped out by the action of the abrupt change of direction at the bottom of tube 328, as previously described.

In the same way as described in relation to Fig 21, the airflow circulating between chamber 364 and chamber 346 in Fig 21 will also be continually stripped of particle/dust content, and air which is generally free of such dust/particle content will rotate sufficiently close to 310, in 364 that it can to the pump 279 via apertures 366.

The absence of the helix 361 in the Fig 21 embodiment means that in general separation efficiencies for the Fig 21 embodiment are not quite so high as can be achieved by the Fig 21 design – but are still very high, and the design is very much simplified with the absence of the rotary seal 311.

Figs 23 and 24 illustrate how the various parts which make up the separator of Figs 21 and 22 can be arranged in a manner which is more suitable for a portable device, which for example may be hand-held, to allow the device to be used in much the same way as a conventional vacuum cleaner.

In Fig 23 the axis of the section containing the particle-collecting bin 320 and housing 321 is angled at approximately 45^0 to the axis of the remainder of the device formed by housings 325 and 365. The arrangement is adapted to be operated with the housing 320 pointing generally down so that the ball 332 will tend to fall away from the valve seat 330 when the airflow through the device ceases. The dust and dirt particles separated by the action of the reversing cyclone in frusto conical tube 328, will tend to occupy the lower

end of the tube and will therefore tend to fall past the ball (when it leaves the valve seat 330) to pass into the bin 320.

Although the duct required to transfer airflow from outlet 340 to inlet 344 is omitted from Fig 21, the arrangement shown in Fig 23 shows how such a duct 343 can be incorporated into a part of the wall of the housing defining the chamber 360. Whereas this region of the structure intermediate housings 321 and 365 is generally cylindrical in form in the Fig 21 embodiment, it is required to have a more complex configuration in the Fig 23 embodiment. Here part of the intermediate region is cylindrical and coaxial with housing 365, so as to accommodate the rotating helix 349, and an integral also cylindrical region 327 extends at 45^0 to the axis of the region 325, to accommodate the apertured end 359 of the hollow shaft 354, and mount the housing assembly 320, 321 at the same angle of 45^0 to the axis of the housing assembly 325, 365.

In other regards the embodiment of Fig 23 operates in a manner similar to that of the Fig 21 embodiment, and the same reference numerals have been employed to denote the parts which are common to the two embodiments, and which function in the manner as described in relation to Fig 21

Fig 24 is similar to Fig 23 but is based in the simpler separator design of Fig 22.

In Fig 24 (as in Fig 23) the axis of the section containing the particle-collecting bin 320 and housing 321 is angled at approximately 45^0 to the axis of the remainder of the device formed by housings 325 and 365. The arrangement is adapted to be operated with the housing 320 pointing generally down so that the ball 332 will tend to fall away from the valve seat 330 when the airflow through the device ceases. The dust and dirt particles separated by the action of the reversing cyclone in frusto conical tube 328, will tend to occupy the lower end of the tube and will therefore tend to fall past the ball (when it leaves the valve seat 330) to pass into the bin 320.

Although the duct required to transfer airflow from outlet 340 to inlet 344 is omitted from Fig 22, the arrangement shown in Fig 24 shows how such a duct 343 can be incorporated into a part of the wall of the housing defining the chamber 360. Whereas this region of the structure intermediate housings 321 and 3165 is generally cylindrical in form in the Fig 22 embodiment, it is required to have a more complex configuration in the Fig 24 embodiment. Here part of the intermediate region is cylindrical and coaxial with housing 365, so as to accommodate the rotating helix 349, and an integral also cylindrical region 327 extends at 45^0 to the axis of the region 325, to accommodate the apertured end 359 of the hollow shaft 354, and mount the housing assembly 320, 321 at the same angle of 45^0 to the axis of the housing assembly 325, 365.

In other regards the embodiment of Fig 24 operates in a manner similar to that of the Fig 22 embodiment, and the same reference numerals have been employed to denote the parts which are common to the two embodiments, and which function in the manner as described in relation to Fig 22.

In the Fig 21 and Fig 22 embodiments the gap between the end face of end 359 and the wall 361 containing the entrance to the frùsto-conical separation tube 328 has been found to affect the separation efficiency of the apparatus. Typically the gap should not be less than 3mm.

In the Fig 22 embodiment it has also been found possible to dispense with the upper separation stage 365 and the return path from 364 to 370, and close off 370, in which event the vacuum pump 279 can communicate directly with the upper end of 354 via a rotary seal, or with the chamber 364 via an outlet passage such as 310 the lower end of which may communicate with the chamber 364 via a perforated end-cap as shown in Fig 22, or simply be open to allow for air to pass directly from chamber 364 into 310. In this latter event there is no requirement for a rotary seal between 354 and 310, merely between 354 and the lower wall 363 of chamber 364 such as is provided by bearing seal 356

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CLAIMS

1. A multistage particle separator comprising at least two separation stages, in which particle-laden air is drawn through a succession of chambers in turn by suction applied to the last of the chambers, heavier than air particles being separated from the airstream in each chamber by centrifugal force, an conveyed to a collecting bin and particle depleted air being drawn from the chamber by suction, wherein an intermediate separation stage comprises:-

(1) a cylindrical chamber,

(2) a port through which air from an earlier stage enters the chamber,

(3) the port being arranged so that air entering the chamber does so generally tangentially,

(4) a hollow spindle extending centrally of the chamber and communicating with an opening in a closed end wall of the chamber, leading to the next separation chamber,

(5) a turbine mounted for rotation about the chamber axis and generally aligned with the port through which air enters the chamber, the incoming air causing the turbine to rotate,

(6) at least one opening at or near the end of the hollow spindle through which air can leave the chamber to pass along the interior of the spindle into the next separation stage, and

(7) a particle collecting region at the end of the chamber remote from the turbine.

2. A multistage separator as claimed in claim 1, wherein the hollow spindle is stationary and the turbine rotates around the spindle.

3. A multistage separator as claimed in claim 1 wherein the turbine is attached to the spindle so that the two rotate together, and a bearing allows for relative rotation between the spindle and the end wall of the chamber.

4. A multistage separator as claimed in any of claims 1 to 3, wherein there are a plurality small openings in the wall of the spindle around one end thereof and the turbine is mounted at a position axially distant from the openings.

5. A multistage separator as claimed in any of claims 1 to 4, wherein the turbine containing region of the chamber is separated from the region of the chamber which communicates with the interior of the hollow spindle, by means of an annular baffle containing at least one opening therein through which air can pass from the one region to the other.

6. A multistage separator as claimed in claim 5, wherein the baffle is stationary relative to the turbine.

7. A multistage separator as claimed in any of claims 3 to 6, wherein the rotating spindle imparts rotation to the air passing therethrough into the next chamber, so that the air is rotating as it leaves the interior of the spindle and enters the next chamber.

8. A multistage separator as claimed in any of claims 1 to 7, wherein a second port is provided in the wall of the chamber circumferentially spaced from the first port, and a passage communicates between an exit from the next stage and the said second port, to allow particles separated from the air passing through the said next stage to be returned to the rotating airstream in the chamber for separation from the returning airstream before passing once again via the hollow spindle to the next stage.

9. A multistage separator as claimed in any of claims 1 to 8, wherein a helical baffle extends radially from the spindle between the region containing the turbine and the region containing the end of the spindle through which air can leave the chamber, so that the rotating airflow leaving the turbine is constrained to follow a helical path thereby imparting an axial component of motion to particles entrained therein, to assist in separating them from the air as it changes direction to enter the spindle to pass to the next stage.

10. A multistage separator as claimed in claim 9, wherein the helical baffle is stationary relative to the chamber.

11. A multistage separator as claimed in claim 9, wherein the helical baffle rotates with the turbine.

12. A multistage separator as claimed in any of claims 8 to 11, wherein the end of the spindle through which air enters the next stage extends into a chamber forming the next stage by means of a hollow cylindrical cap the end of which is closed but the cylindrical wall of which has at least one opening therein through which air can pass into the said next stage.

13. A multistage separator as claimed in claim 12, wherein a cylindrical sleeve concentrically surrounds the cap and has at least one aperture in alignment with the aperture in the cap through which particles leaving the cap in a plane generally perpendicular to the axis of rotation can pass into an annular region between the sleeve and the interior of the chamber, from which they are drawn by suction created by the rotating turbine at the second port in the wall of the turbine containing chamber.

14. A multistage separator as claimed in claim 12 or 13, wherein the cap wall includes a plurality of windows equidistant therearound and the sleeve is formed with a plurality of small openings or perforations in alignment with the rotating windows of the cap.

15. A multistage separator as claimed in claim 12, 13 or 14, wherein the sleeve extends axially internally from one end to the other of the cylindrical chamber of the next stage.

16. A multistage separator as claimed in claim 15, wherein the apertured region of the sleeve only extends axially to the same extent as the cap extends axially into the next stage.

17. A multistage separator as claimed in any of claims 1 to 16, wherein the internal wall of the turbine containing chamber becomes frusto-conical at the end of the chamber remote from the turbine.

18. A multistage separator as claimed in any of claims 1 to 17, wherein the frusto-conical region of the turbine containing chamber leads to a particle collecting region.

19. A multistage separator as claimed in claim 18, wherein a valve is located between the particle collecting region and another particle collecting region, in which particles recovered from the airstream flowing through another stage are stored.

20. A multistage separator as claimed in any of claims 13 to 19, wherein an opening through which particle depleted air is drawn from the chamber of the next stage, is located centrally of an end wall of the cylindrical chamber axially distant from the end thereof through which air enters the chamber from the turbine containing chamber.

21. A multistage separator wherein an intermediate stage includes a rotatable turbine and is constructed and adapted to operate substantially as herein described or with reference to the accompanying drawings.

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Claims searched: 1-21

Examiner: Jason Scott
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Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.T): B2P

Int Cl (Ed.7): B04C

Other: ONLINE: WPI, JAPIO, EPODOC

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X	WPI Abstract Accession No 1998-177332 & RU 2087206 C1 GYAVGYANEN YURIJ (20.08.97) See abstract	1, 17 & 18
X	WPI Abstract Accession No 1993-335367 & SU 1769963 VNI PK I NEFTYANOGO MASH (23.10.92) See abstract	1, 3, 7, 17 & 18
X	WPI Abstract Accession No 1989-157472 & SU 1437094 DO POLITEKH INST (15.11.88) See abstract	1, 3, 7, 17 & 18

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